WIND TUNNEL TEST ON A 1/4.622 FROUDE SCALE, HINGELESS ROTOR, TILT ROTOR MODEL

VOLUME I

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Ames Research Center

by

BOEING VERTOL COMPANY
A DIVISION OF THE BOEING COMPANY
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ABSTRACT

This document is Volume I of four volumes which contain the results of a wind tunnel test of a 1/4.622 Froude scale, hingeless rotor tilt rotor model. The test was performed under NASA Contract NAS2-9015. The test program generated parametric rotor data over the range of nacelle incidences and airspeeds for normal tilt rotor operation up to the equivalent of 300 knots full scale speed. In addition, information on blade loads, rotor/airframe and airframe/rotor interactions and control loads was obtained. Data in hover and transition are presented in Volumes I, II and III and cruise flight data is given in Volume IV.

FOREWORD

This report was prepared by the Boeing Vertol Company of Philadelphia, Pennsylvania for the National Aeronautics and Space Administration, Ames Research Center under NASA Contract NAS2-9015.

Mr. M. A. Shovlin and Mr. T. Galloway of Ames Research Center were technical monitors for this work.

The Boeing program manager was Mr. J. P. Magee. The contributions of the Boeing Vertol Wind Tunnel staff are acknowledged.

The experimental data is presented in four volumes:

NASA CR-151936

NASA CR-151937

NASA CR-151938

NASA CR-151939

This document is volume I NASA CR-151936.

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LIST OF SYMBOLS

SYMBOL	NOMENCLATURE	UNITS
A	Lateral cyclic pitch	Deg
В	Longitudinal cyclic pitch	Deg
b	Span	Ft
CTB-L	Left Rotor Thrust Coefficient	$\frac{\mathbf{T_L}}{\rho \pi \mathbf{R^2 V_T}^2}$
·CPB-L	Left Rotor Power Coefficient	$\frac{\text{HP}_{L} \times 550}{\rho \pi R^{2} V_{T}^{3}}$
CNFB-L	Left Rotor Normal Force Coefficient	$\frac{\mathrm{NF_L}}{\rho\pi\mathrm{R}^2\mathrm{V_T}^2}$
CSFB-L	Left Rotor Side Force Coefficient	$\frac{\text{SF}_{L}}{\rho \pi R^2 V_{T}^2}$
CPMB-L	Left Rotor Pitching Moment	$\frac{PM_{\underline{L}}}{\rho \pi R^3 V_{\underline{T}}^2}$
CYMB-L	Left Rotor Yawing Moment	$\frac{\mathtt{YM}_{\underline{L}}}{p\pi\mathtt{R}^{3}\mathtt{V_{\underline{T}}}^{2}}$
CTB-R	Right Rotor Thrust Coefficient	$\frac{{}^{\mathbf{T}}\mathbf{R}}{\rho\pi\mathbf{R}^{2}\mathbf{V_{T}}^{2}}$
CPB-R	Right Rotor Power Coefficient	$\frac{\text{HP}_{\text{L}} \times 550}{\rho\pi R^2 V_{\text{T}}^3}$
CNFB-R	Right Rotor Normal Force Coefficient	$\frac{NF_{R}}{\rho\pi R^{2}V_{T}^{2}}$
CSFB-R	Right Rotor Side Force Coefficient	$\frac{\text{SF}_{R}}{\rho\pi R^2 V_{T}^2}$
CPMB-R	Right Rotor Pitching Moment	$\frac{PM_R}{\rho\pi R^3 V_T^2}$

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LIST OF SYMBOLS (continued)

SYMBOL	NOMENCLATURE	UNITS
CYMB-R	Right Rotor Yawing Moment	$\frac{\mathtt{YM}_{R}}{\rho\pi\mathtt{R}^3\mathtt{V_{T}}^2}$
CLW-AC	Aircraft Lift Coefficient	Lift 1/2pV ² S
CSFW-AC	Aircraft Side Force Coefficient	$\frac{SF}{1/2\rho V^2S}$
CAFN-AC	Aircraft Axial Force Coefficient	Axial Force 1/2pV ² S
CPMW-AC	Aircraft Pitching Moment	Pitch Moment 1/2pV ² Sc
CYMW-AC	Aircraft Yawing Moment	Yaw Moment 1/2pV ² Sb
CRMW-AC	Aircraft Rolling Moment	Roll Moment 1/2pV ² Sb
ē	Wing Chord	FT
D	Diameter	-
D	Airframe Drag	LB
EI _{FLAP}	Flapwise Bending Stiffness	-
EICHORD	Chordwise Bending Stiffness	· -
FM	Figure of Merit	-
GJ	Torsional Stiffness	-
GW	Gross Weight	LB
НР	Rotor Horsepower	НР
I _{xx} ,I _{yy} ,I _{zz}	Mass Moment of Inertia about the Three Axes	IN-LB SEC ²
I_N	Nacelle Incidence	Deg
Ip	Acceleration Pitch Inertia	-
$^{ m H}_{ m Z}$	Hertz	-

LIST OF SYMBOLS (continued)

SYMBOLS	NOMENCLATURE	UNITS
I*p	Centrifugal Pitch Inertia	-
IPIVOT	Moment of Inertia - Polar	LB-FT
iw	Wing Incidence	Deg
L	Lift	LB
NA	Neutral Axis	
P	Per Rotor Revolution	-
PM	Pitching Moment	FT LB
đ	Freestream Dynamic Pressure $1/2\rho V^2$	LB/FT ²
R	Rotor Radius	FT
r	Radial Location to a Blade Station	FT
RM	Rolling Moment	FT LB
s .	Wing Area	FT ²
SF	Side Force	LB
T	Rotor Thrust	LB
t	Airfoil Thickness	FT
V	Freestream Velocity	FT/SEC
$v_{_{\mathbf{T}}}$	Rotor Tip Speed	FT/SEC
X	Aircraft Propulsive Force	LB
X/R or r/R	Non-Dimensional Radius	-
YM	Yawing Moment	FT LB
α	Angle of Attack	-
αf	Fuselage Pitch Deflection	Deg
· as	Nacelle Shaft Pitch Deflection	Deg

LIST OF SYMBOLS (continued)

SYMBOLS	NOMENCLATURE	UNITS
β	Side Slip Angle	Deg
$\delta_{\mathbf{A}}$	Aileron Deflection	Deg
$\delta_{\mathbf{F}}$	Flap Deflection	Deg
9	Partial Derivative Operator	-
Δ	Increment In Coefficient	-
Δθ	Incremental Blade Pitch	-
ρ	Density of Air	LB SEC ² /FT ⁴
σ	Rotor Solidity $\frac{bcR}{\pi R^2}$	-
ψ	Rotor Azimuth Angle	Deg
⁰ 75	Rotor Blade Collective Pitch at the Three Quarter Radius	Deg
μ	Advance Ratio V/V _T	_
ωα	Wing Torsional Frequency	cps
$^{\omega}$ $_{eta}$	2nd Mode Bending Blade Frequency	-
ω _C	Wing Chordwise Bending Frequency	cps
$^\omega$ L	lst Mode Bending Blade Frequency	-
\mathtt{q}^{ω}	Aircraft Pitch Frequency	cps
$\omega_{\mathbf{v}}$	Wing Vertical Bending Frequency	cps
Ω	Rotor Angular Velocity	-
1 Ω ,2 Ω	Integer Frequency Ratio	-
Ω-ω\$	Lower Blade Lag Rotational Frequency	cps
Ω+ωβ	Upper Blade Flap Rotational Frequency	cps
Ω-ωβ	Lower Blade Flap Rotational Frequency	cps

LIST OF SYMBOLS (continued)

SYMBOLS	NOMENCLATURE	UNITS
ζ_{∇}	Wing Vertical Bending Damping & Critical	-
ζc	Wing Chord Bending Damping % Critical	. -
ζα	Wing Torsion Damping % Critical	-

SUMMARY

This report and the three appendix volumes present the results of a wind tunnel test of a 1/4.622 Froude scale tilt rotor model. This test was performed by the Boeing Vertol Company for the National Aeronautics and Space Administration Ames Research Center under NASA Contract NAS2-9015.

The test was designed to provide parametric force, moment and blade fatigue loads data over the normal anticipated flight range of the tilt rotor aircraft. This was done by selecting seventeen initial flight conditions ranging from hover through transition and out to 300 knots simulated full scale airspeed and measuring the effects of aircraft attitude, rotor control inputs, wing flap deflection and rotor RPM. The information obtained is contained in seventeen data files, four of which are in this volume and the remainder in volumes II, III and IV. Each file contains the experimental results at one flight condition.

The large volume of data produced makes it difficult to summarize. Instead a synopsis of the data is provided in section 2 of this report which demonstrates the quality and scope of the experimental results by means of specific examples.

Load control in cruise was investigated by means of "cyclic on the stick" (Reference 1) and it was found that a single

control law could provide low alternating loads over the cruise speed range.

The data provided needs further analysis and application to the mathematical model used to describe the rotor system in real time simulation by means of regression analyses. In this manner the large bulk of data can be reduced to manageable proportions and provide an understanding of the influence of the important parameters.

This volume contains details of the model, test program and data system and presents four data files in hover and transition. The rest of the transition data can be found in Volumes II and III and the cruise data in Volume IV.

1.0 INTRODUCTION

This document contains wind tunnel test data obtained on a 1/4.622 scale dynamically similar model of a tilt rotor aircraft which has composite hingeless blades. The test was performed under NASA contract NAS2-9015.

The objective of the test was to generate information on the behavior of rotor and airframe effects over a range of flight parameters representing the complete operating envelope of the tilt rotor vehicle. The information which was required included the magnitude and sensitivity of:

- (1) Rotor forces and moments
- (2) Blade loads and pitch link loads
- (3) Wing rotor interference effects
- (4) Airframe forces and moment for values of such flight parameters as:
 - (1) Nacelle tilt angle
 - (2) Forward speed
 - (3) Aircraft attitude in pitch and yaw
 - (4) Collective and cyclic pitch control
 - (5) Wing flap deflection

The selection of test points and true variations for parameters was made in such a way that a comprehensive set of data was obtained for all potential flight conditions through hover, a wide envelope of transitions, and cruise at speeds up to 300 knots.

The purpose of this acquisition of comprehensive rotor and airframe test data is to provide the knowledge and basis for understanding rotor and airframe behavior which is an essential prerequisite to the development of an efficient system of integrated rotor and aircraft controls.

A secondary objective of the test was to determine the feasibility of a control system which minimizes blade loads in cruise. The characteristic feature of this system is the use of cyclic pitch geared by a simple mechanical linkage to the motion of the stick and control surfaces. These must be properly phased and scheduled to achieve good flying qualities in all flight regimes, subject to the overall design requirement of an optimal control system to maintain simplicity and reliability as far as is consistent with the loads, maneuver envelope and flying qualities of the aircraft.

The rotor controls provide a major portion of the control capability from hover through the low transition speed range, although the conventional control surfaces are operative in all regimes of flight including hover. As speed is increased, and the aerodynamic surfaces become effective for trim and control, the rotor controls can be directed at minimizing rotor loads. In cruise the problem reduces to determining the rotor control required to maintain minimum loads. Prior to this test, a limited amount of full scale experimental data existed for transition, and for cruise up to speeds of 192

knots (Reference 2). This test program extends the range of this data in the transition regime, and in cruise flight the range was extended up to the simulated speed of 300 knots.

The data obtained on this test goes a long way toward providing the information which is necessary to tackle the job of designing an optimized and integrated control system for a tilt rotor aircraft using a soft inplane hingeless rotor.

Work which remains to be done involves reducing the data obtained in the test, to an analytical format with forces, moments, loads, etc., expressed as functions of the relevant flight parameters. This is necessary for two reasons:

- (1) to provide an understanding of the significance and relative importance of the parameters which will permit efficient planning of future full scale tests
- (2) to provide a set of simple functions representing the body of test data, from which the rotor effects may be calculated within the context of a real time simulation

This reduction of the test data to analytical functions of the parameters is beyond the scope of the current contract. It is planned that this additional step will be accomplished in the near future under separate funding.

The data obtained during this test is presented in four volumes.

Volume I contains a detailed description of the model, the test installation, test procedures and data reduction: for the convenience of the user, an abbreviated discussion of these is included in Volumes II, III and IV. It was felt that the amount of data generated was too voluminous to be readily presented in a single volume, and Volumes II, III and IV present all the data in a logical sequence.

2.0 SYNOPSIS OF RESULTS

The scope of the test program is sufficiently large that a comprehensive analysis and review of the test data would be a major undertaking. The analysis, correlation and modelling of the experimental information is beyond the scope of the contractual work reported here; however, some examples have been taken and correlation effected to provide some insight as to the range and validity of the information available.

The primary objective of the test was to measure force and moment parametrics over the flight range. The examples discussed in the following paragraphs provide an indication of the range and validity of the experimental data.

The normal force produced by a lateral cyclic (test axes system) control input is shown as a function of rotor shaft angle in hover and transition in figures 1 and 2.

In hover, the derivative is over predicted by the real time mathematical model of the rotor system (Ref. 7). Correlation is good at 45 knots (full scale) and 100 knots (full scale). The 100 knot (full scale) data also shows good agreement with the data point taken from full scale tests in the NASA-Ames 40' x 80' wind tunnel performed in 1972 (Reference 2). Similar correlation is apparent at 140 knots, Figure 2; however, at 180 knots a discrepancy in the curve shape is evident.

In cruise, with almost axial flow conditions, the magnitude of the $\partial \text{CN}/\partial A_1$ derivative should be equal to $\partial \text{CSF}/\partial B_1$ from considerations of symmetry. Figure 3 shows the measured derivative data as a function of forward speed out to 300 knots (full scale). Three data points taken from full scale tests (Reference 2) are superimposed and show good agreement. The line shown is the $\partial \text{CN}/\partial A_1$ derivative as computed from the real time simulation math model and indicates an adequate representation of the experimental data.

The effect of B₁ cyclic on normal force in transition is shown in figures 4 and 5. In hover the derivative is under predicted. Referring back to the A_1 data (figure 1) it is possible to compare the resultant force magnitude due to cyclic from both test and the math model. The test indicates a 9% increase in control power over the math model representation; however, there is a discrepancy in the azimuthal angle at which the control input must be made which needs to be resolved. The $\partial CN/\partial B_1$ derivative is under predicted at both 45 and 100 knots, although the functional variation with angle of attack has clearly the correct form. knots (figure 5) the correlation of the math model representation is good at the higher values of α . A discrepancy exists between the model data and the full scale data of Reference 2 needs further examination. The data at 180 knots display a similar trend to the Al derivative data of figure 2 and need a modification of the math model to adequately describe the data in this area of the envelope.

The cruise $\partial CN/\partial B_1$ derivatives are of the same magnitude as the $\partial CSF/\partial A_1$ derivatives again from symmetry and are plotted as a function of forward speed in figure 6. The data agree well with both the real time simulation math model and the 40' x 80' tunnel test data (Reference 2).

The behavior of the rotor hub pitching moment derivative with B_1 cyclic pitch in hover and transition is provided in figures 7 and 8. The hub moment data are under predicted by the simple model and the data show an initial rise due to angle of attack not adequately accounted for in the simulation representation. The conditions where full scale data are available from Reference 2 again show good agreement with the model scale data.

The hub pitching moment due to B_1 cyclic are the same magnitude as hub yaw moment due to A_1 cyclic in symmetrical in flow conditions. Figure 9 shows a comparison of the measured data out to 300 knots (full scale).

For an isolated rotor the derivative of rotor normal force with shaft angle of attack would be expected to be of the same magnitude as the side force due to yaw angle from symmetry considerations. This symmetry is disturbed on the airplane by the interference effects of the airframe, primarily due to the wing circulation induced velocities at the rotor. The

derivatives of normal force with angle of attack and side force with yaw angle are plotted as functions of forward speed in figure 10. The amplification of the normal force derivative due to airframe/rotor interference is clearly visible. The simulation math model does an adequate job of predicting the total normal force derivative.

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The rotor hub pitching moment derivative with angle of attack data is shown for cruise conditions in figure 11 and clearly indicates a sign reversal at approximately 220 knots. this airspeed the rotor hub moment is a stabilizing influence on the aircraft. The model scale data agree well with full scale test results; however, the real time math model does not take advantage of the stabilizing effect. The pitch moment due to yaw is shown in figure 12 and shows good correlation up to 220 knots full scale. The correlations due to deteriorates beyond this airspeed. Alternating blade bending loads occur on the blade as a result of the one per rev forcing produced by inclination of the rotor shaft to the airstream. Figures 13 and 14 show the increase in sensitivity of alternating blade chord and flap bending loads as airspeed increases. The data agree well with full scale data. The application of cyclic pitch control in cruise also causes one per rev forcing of the blade modes. The bending loads per degree of cyclic in cruise are shown in figure 15 and indicate an approximately constant sensitivity over the cruise flight range.

One of the objectives of the test program was to test the "cyclic on the stick" control as a means of blade load alleviation in cruise flight. This system introduces cyclic pitch as a function of longitudinal stick position in cruise to trim out the one per rev loads in much the same manner as is done on a helicopter in forward flight. It should be noted that this system is <u>not</u> an adaptive feedback controller but a straight forward link between stick position and rotor controls.

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Figure 16 shows the resultant alternating blade bending moments measured on angle of attack sweeps plotted as a function of maneuver load factor at 140 knots for three different sets of conditions. The load levels which correspond to 10⁸ cycles and 10⁷ cycles (mean - 3\sigma) fatigue life from reference 3 are shown superimposed. For 1g level flight at this speed, the aircraft trims at a nose up attitude and would produce alternating load levels of about 4630 N-m (41,000 in lbs) if no cyclic pitch is used. Tests were performed where cyclic pitch was introduced as a function of angle of attack in an attempt to match the cyclic pitch - angle of attack relationship produced by the cyclic pitch on the stick design of reference 1. The schedules did not match precisely. This test shows a reduction in rotor blade fatigue loads of about 25% at 1g level flight.

A third test was made to determine the optimum cyclic schedule and the loads resulting from it and this is shown in figure 16 as the minimum loads cyclic schedule line. Similar data is shown in figure 17 for 220 knots full scale. In this case the lg trim angle of attack is a small nose up angle and the "no cyclic" loads would provide less than 10⁸ cycles level up to 1.46g's. The precalculated cyclic schedule would increase the g range within this load level to approximately 1.9g's.

If the optimum cyclic pitch schedule were used then the loads can be maintained at 28% of the 10⁸ cycles level up to and beyond a 2g maneuver. At 260 knots (full scale) figure 18, the aircraft can pull 1.9g's with less than 10⁸ cycles (m - 3σ) loads. With the pretest calculated cyclic schedule the loads at 1.9g's reduce to approximately 2598 N-m (23,000 in lbs) or 65% of the 10⁸ cycles (m - 3σ). At 300 knots full scale (figure 19) the pretest schedule provides loads less than 10⁸ cycles (m - 3σ) from 1g out to at least 2.3g's.

The cyclic pitch required to minimize the alternating loads at any angle of attack (or load factor) can be deduced from the test data obtained. Figure 20 shows the cyclic pitch levels required for minimum loads as a function of longitudinal stick position which can be related to airplane angle of attack by means of the simulation model. It is clear that no single relationship between cyclic pitch and stick position will provide optimum loads over the entire range; however, judicious selection of a control law can provide loads well

within the fatigue limits. The heavy line drawn through the data is one such law which has been selected so as to pass through the lg points and is biased towards the low speed conditions. If this cyclic control law were used then the loads would reduce as shown in figures 21, 22 and 23 at 140, 220 and 300 knots (full scale) respectively. For lg level flight, the loads are never greater than 30% of the 108 cycles (m - 30) load level and at 2g's are still within 73% of that level. These data are pertinent to a given gross weight, altitude and CG position and would change at other operating conditions. Further analysis needs to be performed to examine the impact of these considerations; however, the test has shown that a control system of this type can be an extremely powerful means of maintaining low fatigue loads.

The design rotor diameter of the XV-15 Tilt Rotor Research Aircraft is 7.6 m (25 ft.). If the Boeing 7.9 m (26 ft.) rotor were to be flown on that aircraft, a reduction of tip clearance of 75.2 cm (6 in.) could result. A run was made to assess the impact of tip clearance on blade loads by fitting a "scab-on" bulge on the side of the model fuselage to reduce the tip clearance. The loads measured with and without the bulge fitted are shown in Figure 24 and no effect on load level is in evidence.

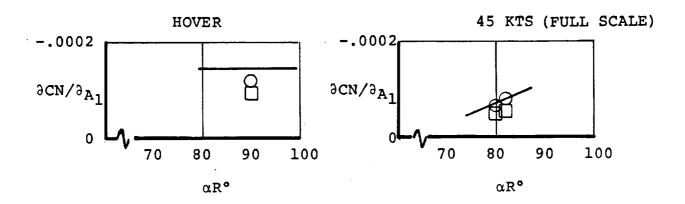
During the development of the XV-15, model tests discovered the presence of an unstable yaw derivative at small yaw angles

in cruise which contributed to the decision to use an H tail. Figures 25, 26 and 27 show yaw derivatives for the model tested in this program and show a stable slope at all conditions.

The preceeding data and discussion is by no measure a complete evaluation of the test data obtained on the program reported in this and the appendix volumes; however, it does serve to provide an overview of the extent and quality of the experimental data obtained.

NORMAL FORCE DUE TO CYCLIC PITCH

O LEFT ROTOR RIGHT ROTOR •40'x80' DATA MATH MODEL



NOTE: TEST CYCLIC AXES SYSTEM USED

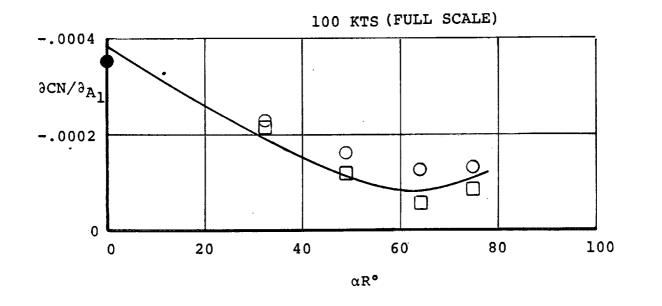
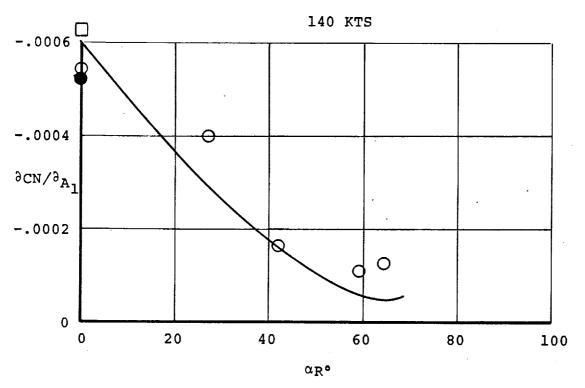


Figure 1. Rotor Normal Force Due to ${\rm A}_1$ Cyclic in Hover, 45 and 100 Knots.

NORMAL FORCE DUE TO CYCLIC PITCH

OLEFT ROTOR □RIGHT ROTOR ■40'x80' DATA — MATH MODEL



NOTE: TEST CYCLIC AXES SYSTEM USED

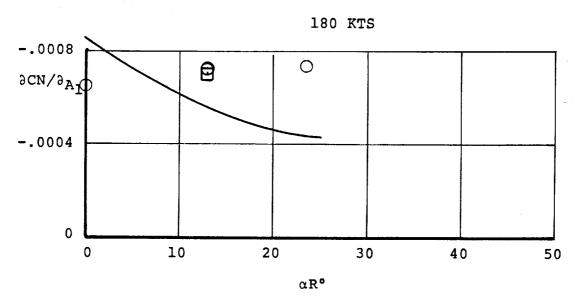
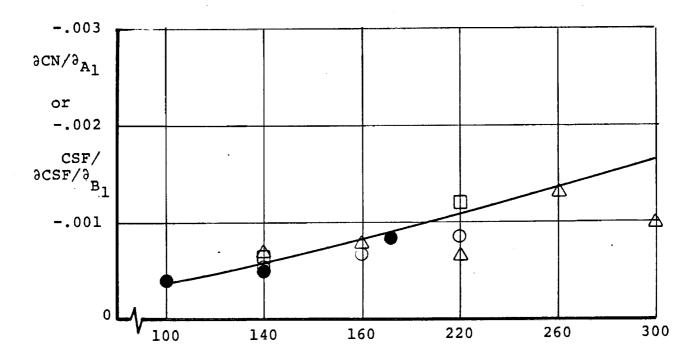


Figure 2. Rotor Normal Force Due to ${\rm A_1}$ Cyclic at 140 and 180 Knots in Transition.

NORMAL FORCE DUE TO CYCLIC PITCH

 $\partial \text{CN}/\partial_{\text{A}_1}$ Oleft rotor igoplus 40'x80' data — Math Model \triangle side force data



AIRSPEED ∿ KTS

NOTE: TEST CYCLIC AXES SYSTEM USED

Figure 3. Rotor Normal Force Due to A_1 Cyclic and Blade Force Due to B_1 Cyclic in Cruise.

NORMAL FORCE DUE TO CYCLIC PITCH $\partial CN/\partial_{B_1}$

O LEFT ROTOR ☐ RIGHT ROTOR ● 40'x80' DATA MATH MODEL HOVER 45 KNOTS -.0002 -.0002 ∂CN/∂_B1 ∂CN/∂B₁ 70 100 70 80 90 100 80 90

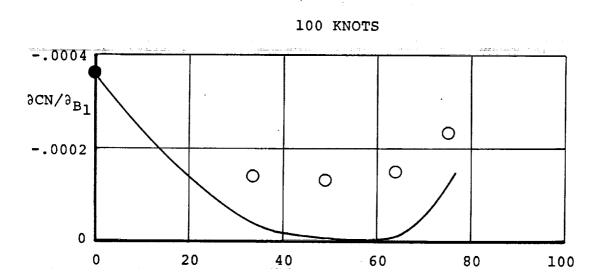


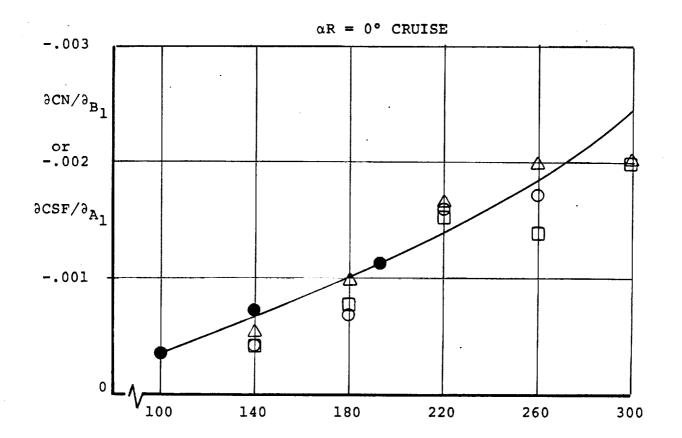
Figure 4. Rotor Normal Force Due to B₁ Cyclic Pitch in Hover and Transition.

NORMAL FORCE DUE TO CYCLIC PITCH OCN/OB1 ORIGHT ROTOR LEFT ROTOR 40'x80' DATA — MATH MODEL -.0008 140 KTS -.0006 ∂CN/∂_{B1} -.0004 -.0002 80 100 20 40 60 Ø αR° -.001 180 KTS 0 9CN/9B1 -.0005 20 NOTE: TEST AXES CYCLIC SYSTEM USED

Figure 5. Rotor Normal Force Due to B₁ Cyclic Pitch in Transition.

NORMAL FORCE DUE TO CYCLIC PITCH $\partial CN/\partial_{B_1}$

○ RIGHT ROTOR ☐ LEFT ROTOR ● 40'x80' DATA — MATH MODEL



AIRSPEED ∿ KNOTS

Figure 6. Rotor Normal Force Due to B_1 Cyclic and Side Force Due to A_1 Cyclic in Cruise.

HUB PITCH MOMENT DUE TO CYCLIC PITCH 3CPM/3B1

○ RIGHT ROTOR ☐LEFT ROTOR ●40'x80' DATA — MATH MODEL

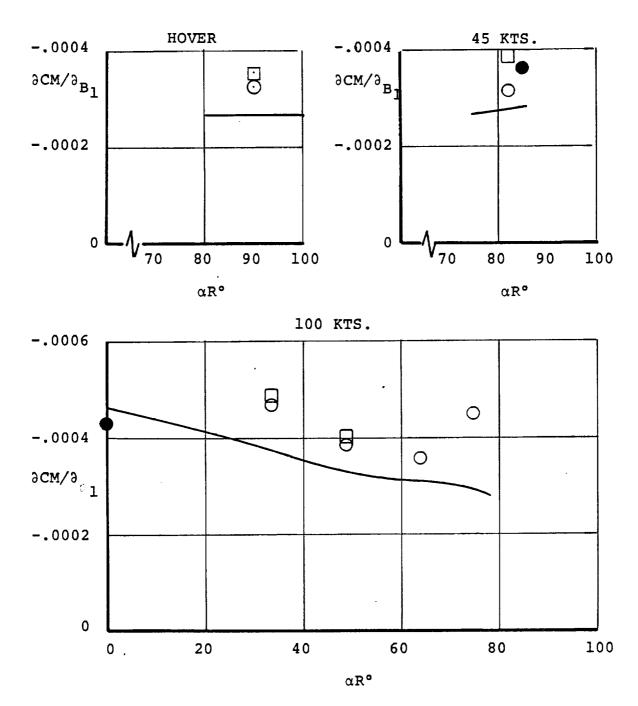


Figure 7. Rotor Hub Pitching Moment Due to B₁ Cyclic in Hover and Transition.

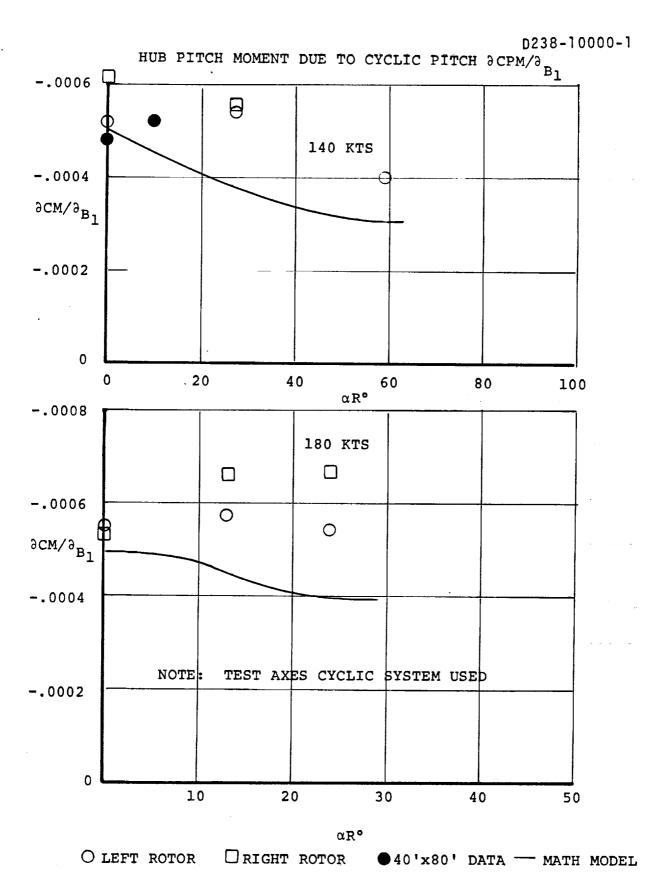
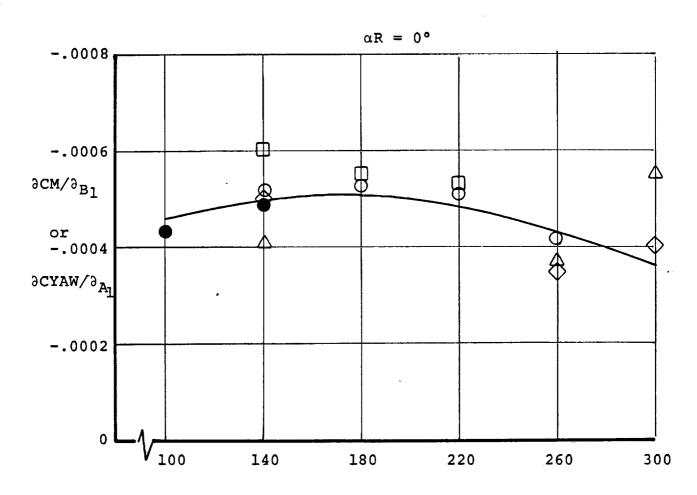


Figure 8. Rotor Hub Pitching Moment Due to B₁ Cyclic in Transition.

HUB PITCH MOMENT DUE TO CYCLIC PITCH OCPM/OB1

- O LEFT ROTOR PITCH DATA
 RIGHT ROTOR PITCH DATA
- △ RIGHT ROTOR YAW DATA
- 40'x80' DATA

--- MATH MODEL



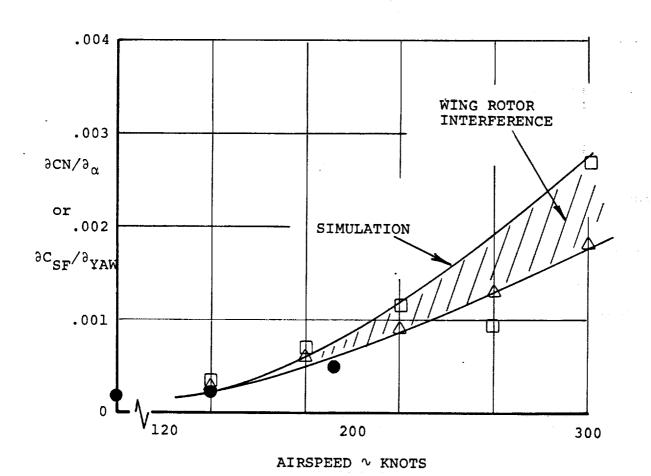
AIRSPEED ∿ KNOTS

Figure 9. Rotor Hub Pitch Moment Due to B_1 Cyclic and Yaw Moment Due to A_1 Cyclic in Cruise.

CRUISE DATA

- □ NORMAL FORCE DATA

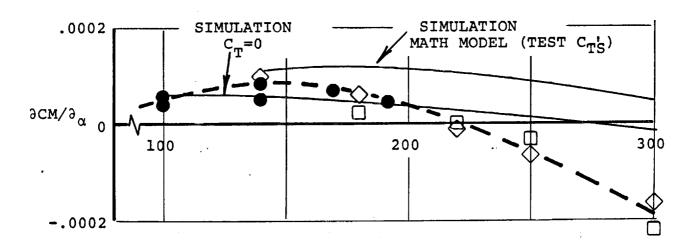
 △ SIDE FORCE DATA
- 40'x80' DATA



NOTE: TEST AXES CYCLIC SYSTEM USED

Figure 10. Rotor Normal Force Due to α and Side Force Due to Yaw Angle in Cruise.

CRUISE DATA



AIRSPEED ∿ KNOTS

- _ LEFT ROTOR
- RIGHT ROTOR
- 40'x80' DATA

Figure 11. Rotor Hub Pitching Moment Due to Angle of Attack.

CRUISE DATA

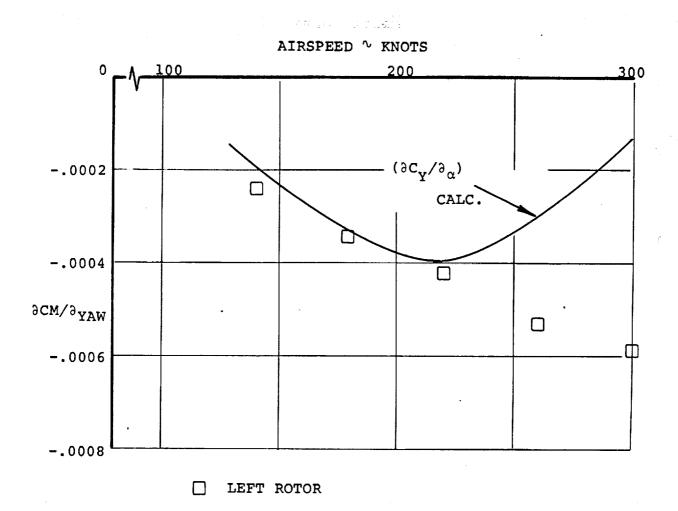
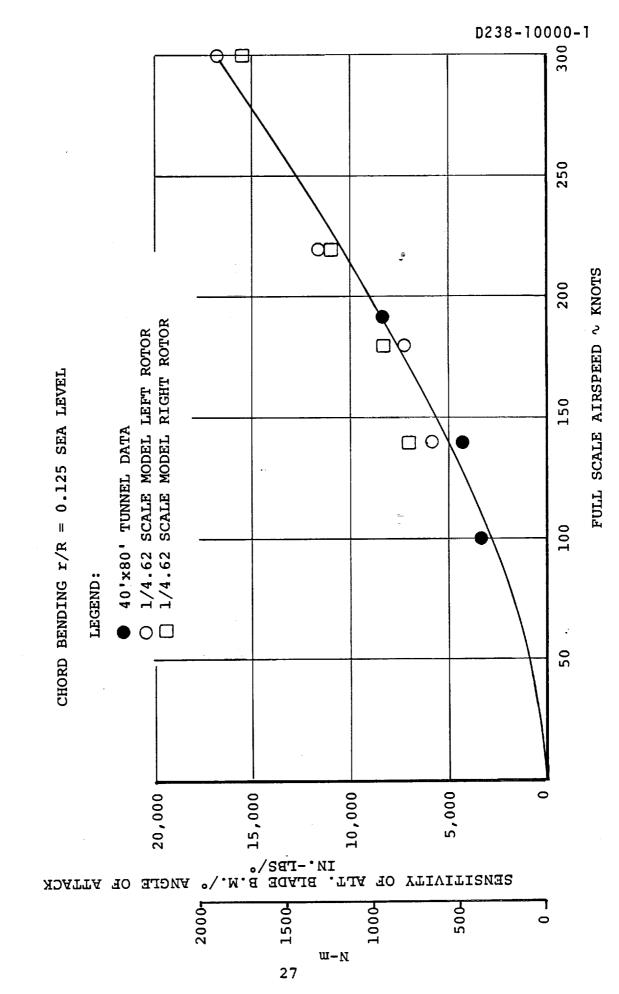
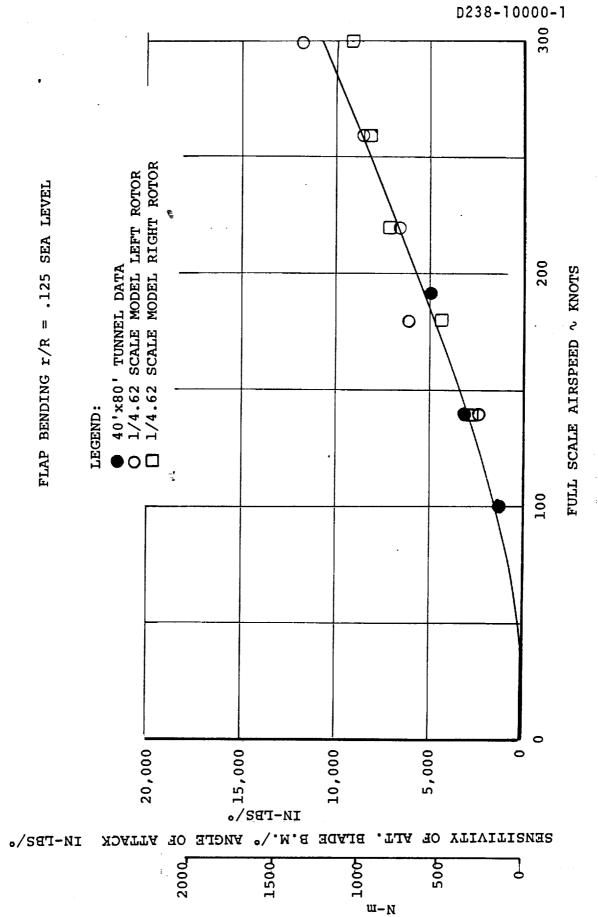


Figure 12. Rotor Hub Pitch Moment Due to Yaw Angle.



Sensitivity of Alternating Blade Chord Bending Coments to Angle of Attack in Cruise. Figure 13.



Sensitivity of Blade Flap Bending Moments in Cruise. Figure 14.

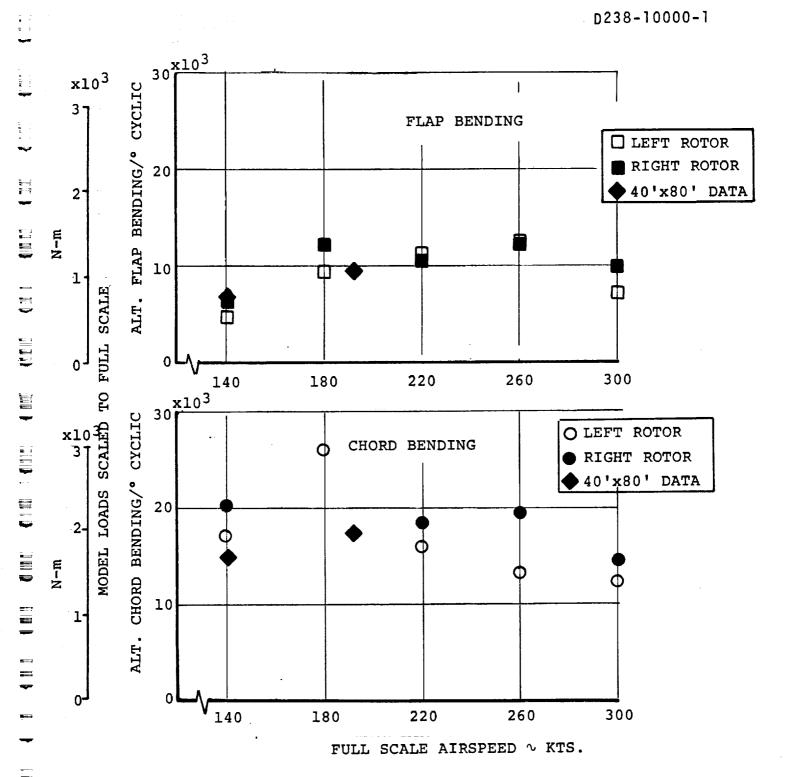
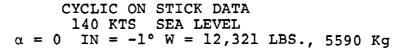


Figure 15. Sensitivity of Blade Bending Loads to Cyclic Pitch - Cruise.



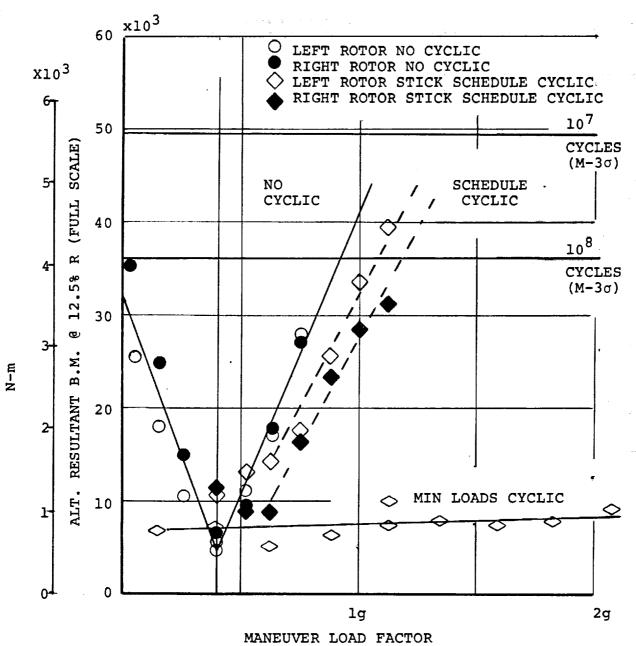
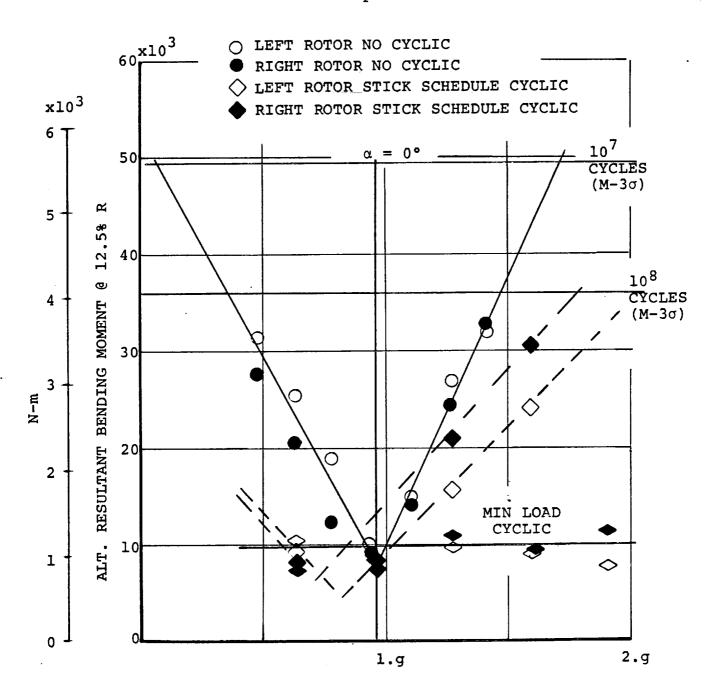


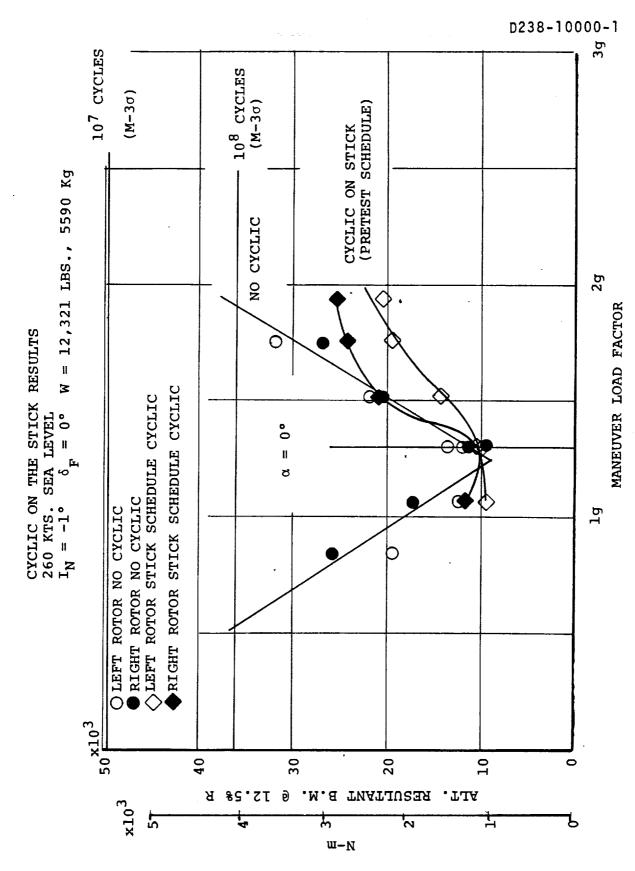
Figure 16. Alternating Blade Loads in Cruise With and Without Cyclic Pitch at 140 Knots (Full Scale).

CYCLIC ON THE STICK RESULTS FULL SCALE AIRSPEED 220 KTS IN = -1° $\delta_{\rm F}$ = 0° W = 12,321 LBs., 5590 Kg



MANEUVER LOAD FACTOR

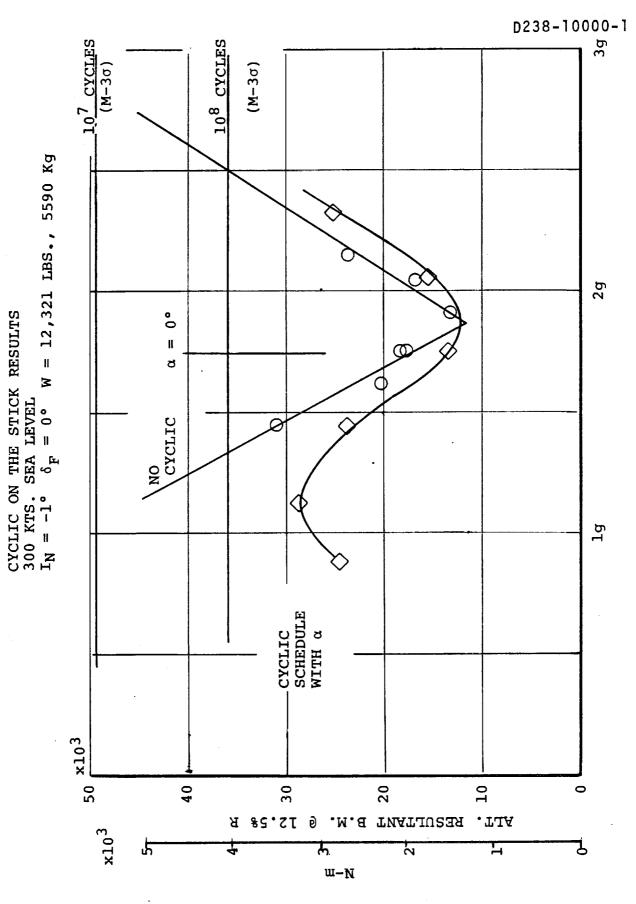
Figure 17. Alternating Blade Loads in Cruise With and Without Cyclic Pitch at 220 Knots (Full Scale).



Alternating Blade Loads in Cruise With and Without Cyclic, Pitch at 260 Knots (Full Scale). Figure 18.

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Alternating Blade Loads in Cruise With and Without Cyclic Pitch at 300 Knots (Full Scale). Figure 19.

MANEUVER LOAD FACTOR

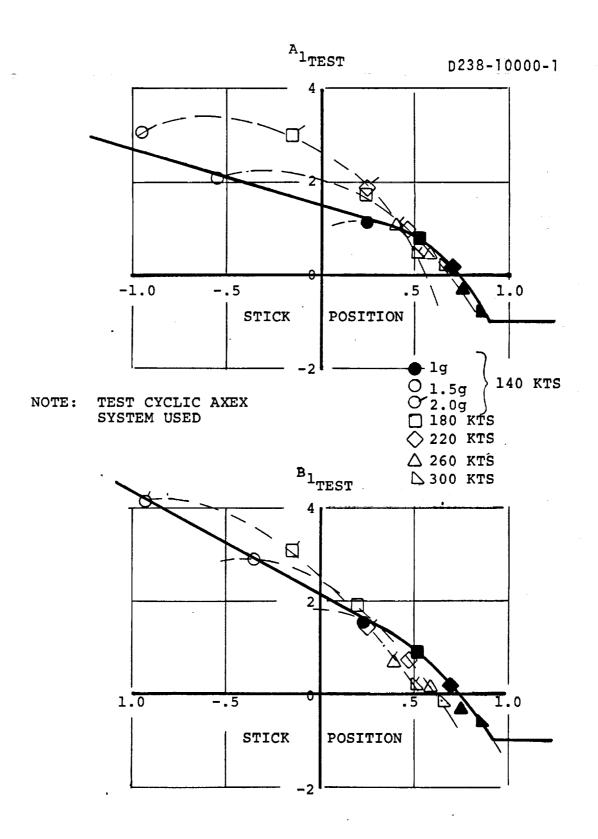


Figure 20. Cyclics Required for Minimum Loads in Cruise.

CYCLIC ON STICK DATA 140 KTS SEA LEVEL $\alpha = 0$ IN = -1° W = 12,321 LBS., 5590 Kg

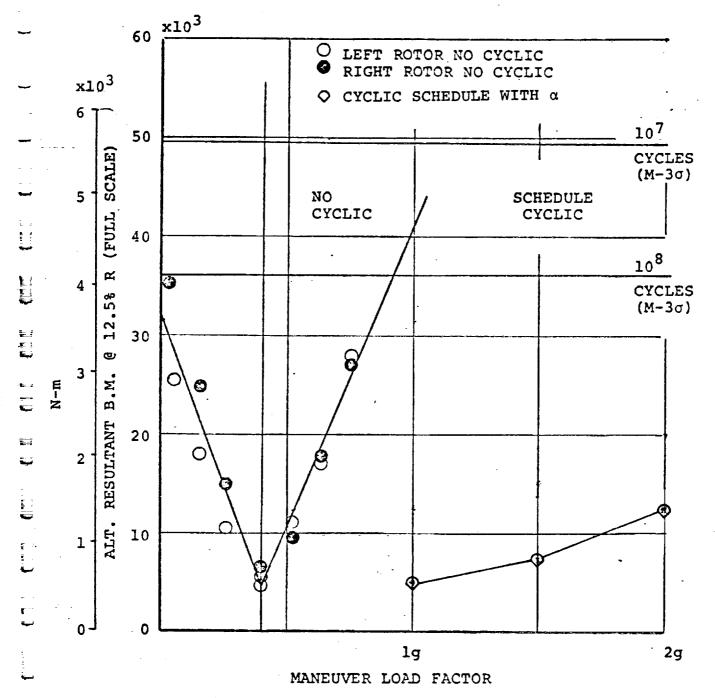
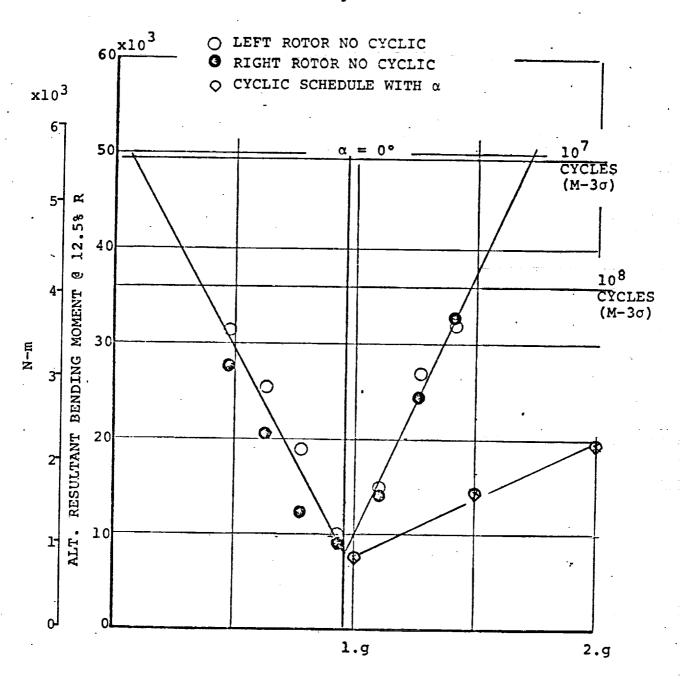


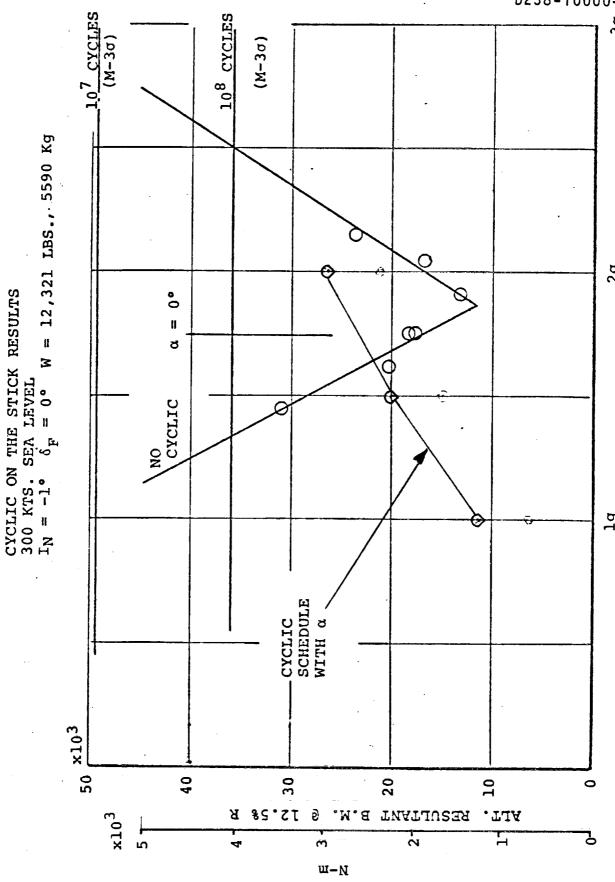
Figure 21. Loads With Test "Cyclic On Stick" 140 Knots Full Scale.

CYCLIC ON THE STICK RESULTS FULL SCALE AIRSPEED 220 KTS IN = -1° $\delta_{\rm F}$ = 0° W = 12,321 LBs., 5590 Kg



MANEUVER LOAD FACTOR
LOADS WITH TEST "CYCLIC ON STICK"

Figure 22. Loads With Test "Cyclic on Stick" 220 Knots Full Scale.



Loads With Test "Cyclic On Stick" 300 Knots Full Scale. MANEUVER LOAD FACTOR Figure 23.

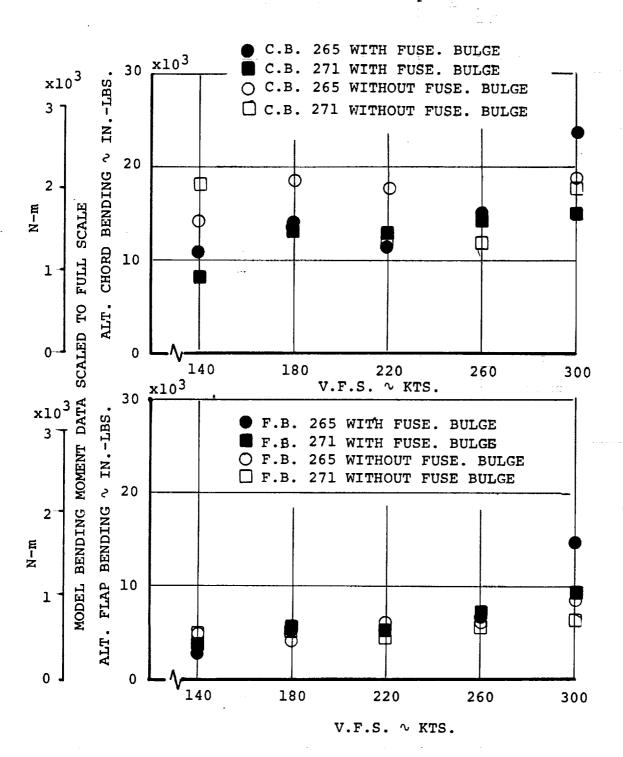
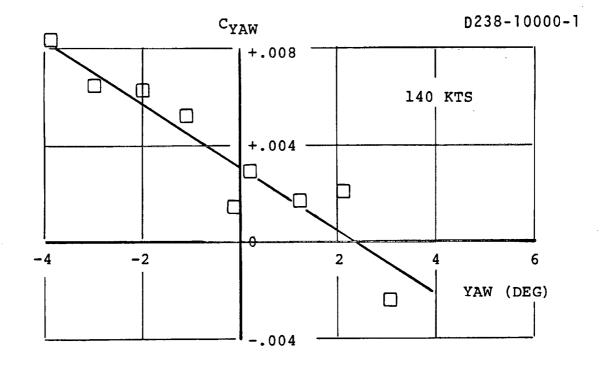


Figure 24. The Effect of Fuselage - Blade Tip Clearance on Alternating Blade Loads in Cruise.



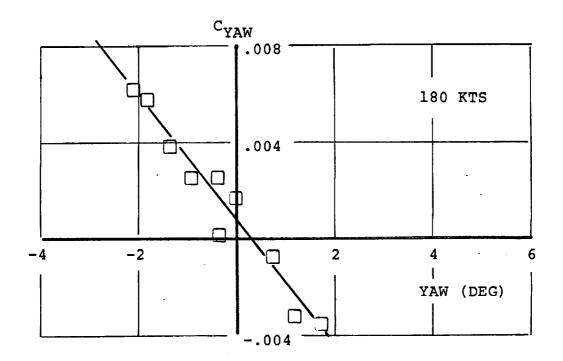
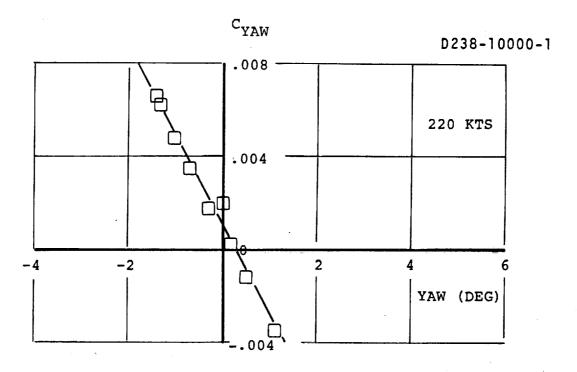


Figure 25. Aircraft Yaw Moment Coefficient as a Function of Yaw Angle in Cruise at 140 and 180 Knots Full Scale.



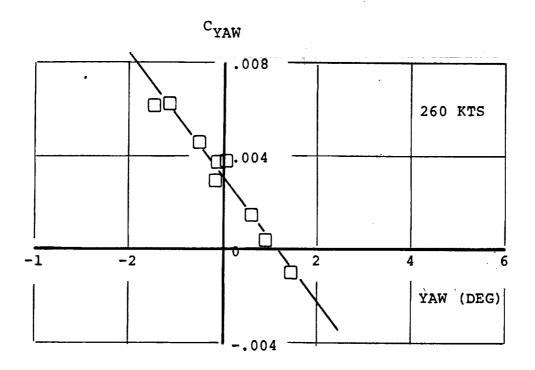


Figure 26. Aircraft Yaw Moment Coefficient as a Function of Yaw Angle in Cruise at 220 and 260 Knots Full Scale.

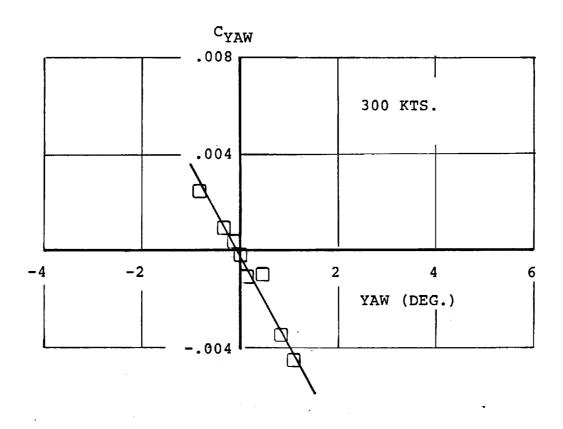


Figure 27. Aircraft Yaw Moment Coefficient as a Function of Yaw Angle in Cruise at 300 Knots Full Scale

3.0 TEST EQUIPMENT AND INSTALLATION

This section of the report serves to document the details of the test model, the model mount in the wind tunnel, the sign conventions and scale factors which apply to the test, the instrumentation and the data reduction procedures adopted.

3.1 Model Description and Instrumentation

The model tested is a 1/4.622 scale full span, powered configuration that is Froude scaled of the Model 222 Tilt Rotor Research aircraft. This model, shown in Figure 28 was provided by Boeing/Vertol for this test program and has the following major dynamically-scaled components.

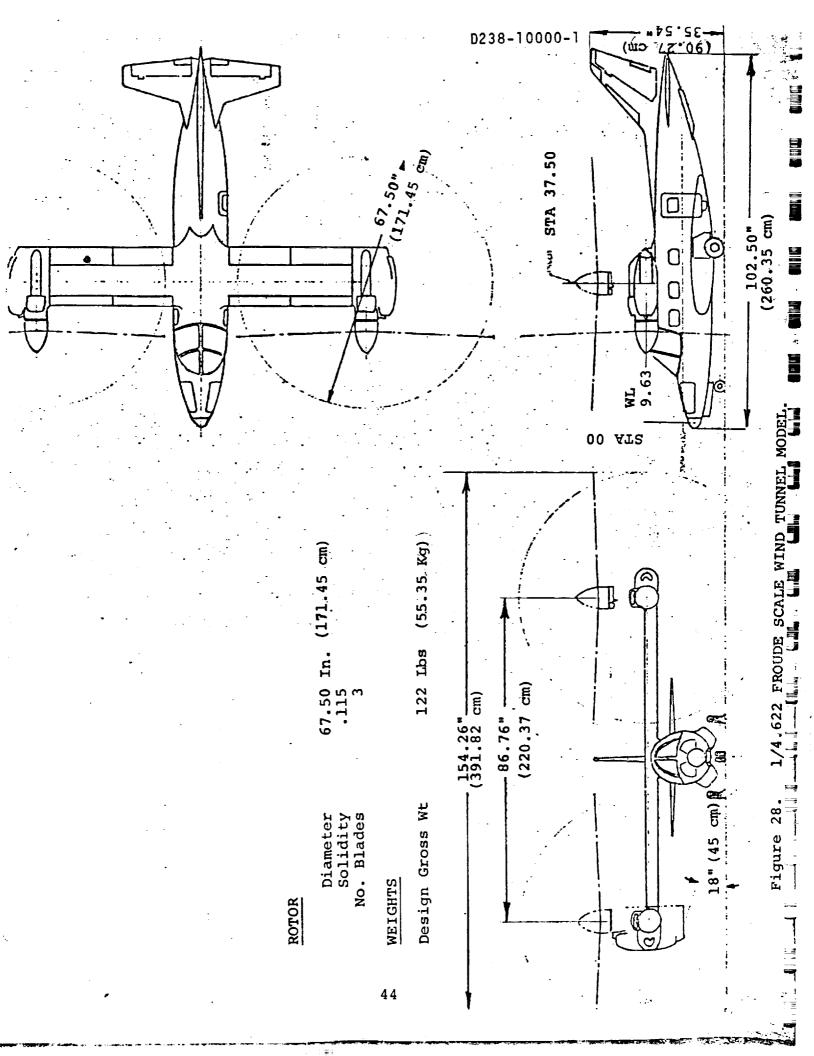
- 1. Two 3-bladed rotors
- 2. Two nacelles
- 3. Full span wing
- 4. Fuselage
- 5. Tail

Photographs of the model in hover, transition and cruise flight conditions are shown in figures 29, 30 and 31.

Basic model dimensions are shown in Table 1.

The nacelles are joined to the wing by a pivot and have remote pitch actuation.

The wing is crown mounted and has full span flaps and leading edge umbrellas for download alleviation. Flaps are used during transition to provide additional lift and the outboard section



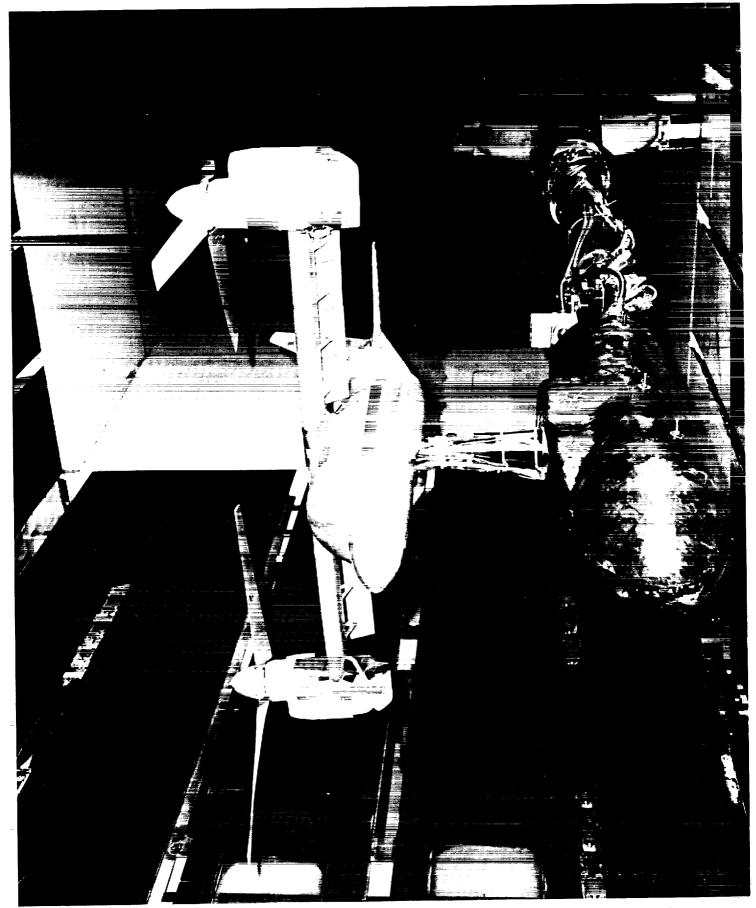


Figure 29. 1/4.622 Scale Model Installed in the Wind Tunnel Test Section (Hover)

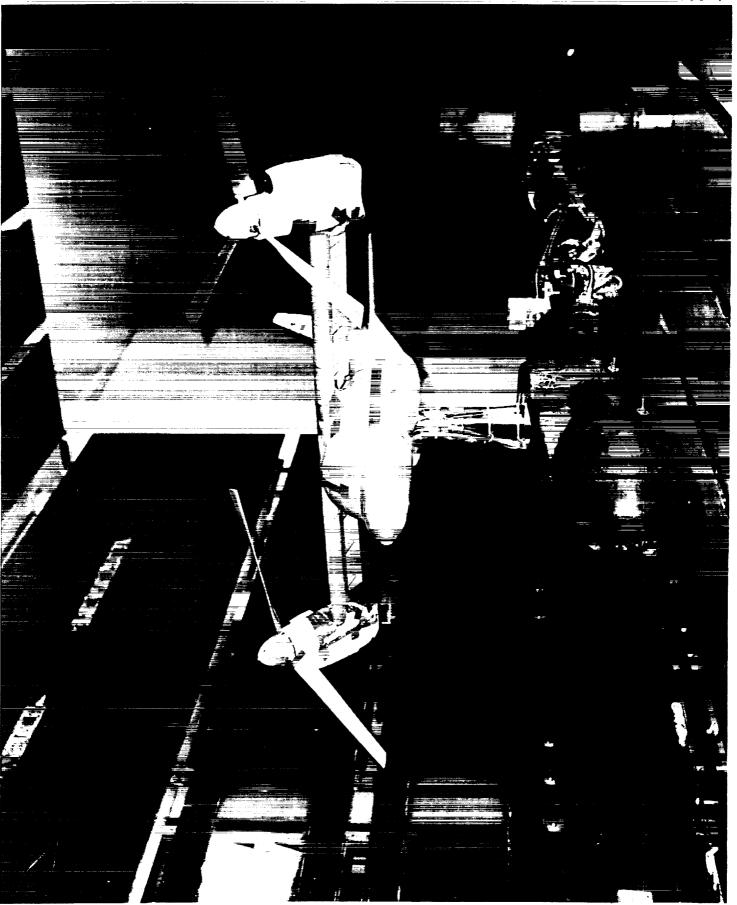


Figure 30. 1/4.622 Scale Model Installed in the Wind Tunnel Test Section (Transition)

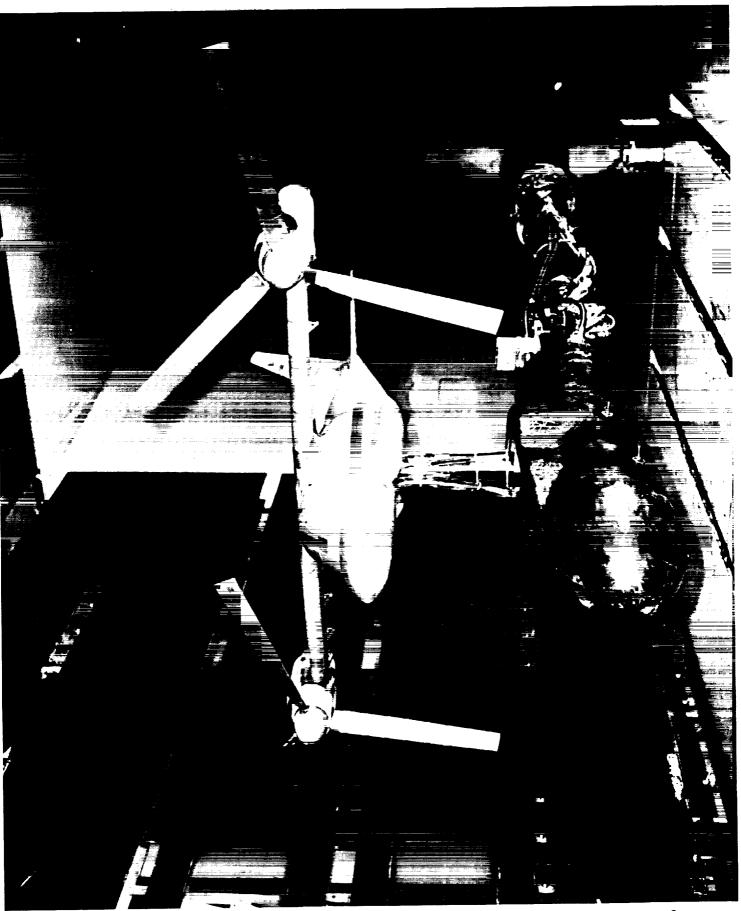


Figure 31. 1/4.622 Scale Model Installed in the Wind Tunnel Test Section (Cruise)

TABLE 1

MODEL DIMENSIONS

ROTOR

Number of Blades
Radius
Chord
Twist
Airfoil Section
Solidity
Rotor Speed (Hover)
Rotor Speed (Cruise)
Collective Pitch Available
Cyclic Pitch Available

NACELLE

Nacelle Pivot Position (in % of Wing Chord) Rotor Disc Nacelle Pivot Distance

WING

Airfoil Section

Span (Rotor & to Rotor &)

chord

Area

Aspect Ratio

Flap in % of Chord

Wing Incidence

Thickness - Chord Ratio

FUSELAGE

Diameter Length

TAIL - HORIZONTAL

Area
Span
Aspect Ratio
Taper Ratio (CTIP/CROOT)
Root Chord
Airfoil Section
Elevators in % of Chord

3
33.75 IN. (85.72 cm)
4.078 IN. (10.35 cm)
42.5 DEG.
23021/23010-1.58
0.115
1185 RPM
825 RPM
-5 to 65 DEG.
+ 10 DEG.

.40%

12.33 IN. (31.31 cm)

63₄221 Modified

86.76 IN. (220.37 cm) 15.53 IN. (39.44 cm) 9.36 FT.² (.869 M²) 5.61

2 DEG. 0.21

14.69 IN. (37.31 cm) 102.50 IN. (260.35 cm)

2.73 FT.² (.253 M²) 10.89 IN. (27.66 cm)

4.25

14.05 IN. (35.68 cm)

64A010 44.1%

TABLE 1 (continued)

TAIL - VERTICAL

Area	ı		2.03 FT ²	$(.185 \text{ m}^2)$
Span		• •	22.75 IN.	(57.78 cm);
Aspect! atio			1.77	/
Taper Ratio (CTIP/CROOT)			.35	
Root Chord			20.98 IN.	(58.29 cm)
Airfoil Section			64A008	
Rudder in % of Chord			50.6	

of the flap is used as an aileron for control in conjunction with outboard spoilers.

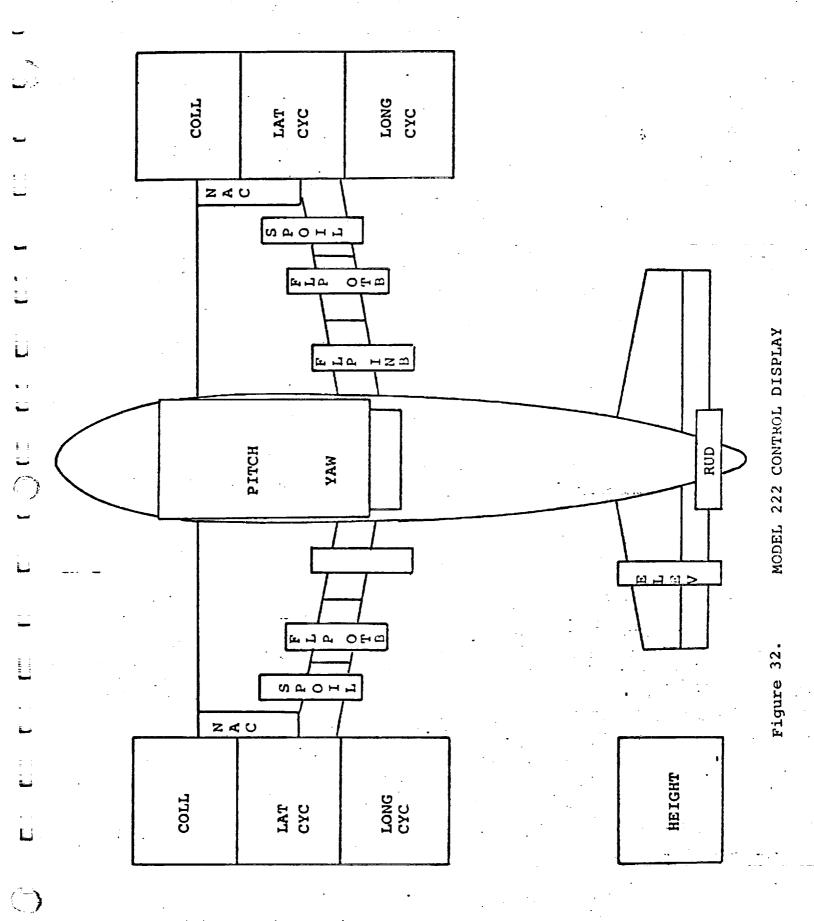
The wing, fuselage, and empennage are dynamically scaled from the Model 222 tilt rotor aircraft and the rudder and elevator and flaps are remotely controlled.

The model is powered by a 20 HP, 11,375 RPM electric motor manufactured by Task Corporation. The motor drives a 3.04:1 reduction gear box in the center fuselage which is connected by cross shafts in the wing to a 3.09:1 reduction gear box in each nacelle. This provides a total gear reduction from the electric motor to rotor of 9.39:1.

The model control station is shown schematically in figure 32 as comprised potentiometer controls and beep switches with analogue meters for readout in the format depicted.

The rotor controls provided collective and two axes of cyclic pitch on each rotor driven by potentiometers at the control station using simple position feedback control, the actuator follow up potentiometer output being used to provide readout to the operator.

The position of the actuators in the rotor azimuth together with the 18.4° between the pitchlink rod end and the blade 1/4 chord defines the cyclic pitch control axes as shown in figure 33. Thus for a longitudinal or B_1 input the maximum



blade angle occurs at 150.4° and 330.4° azimuth. The lateral or A_1 axis is orthogonal to B_1 . When a positive B_1 command is made the maximum blade angle is at $\psi = 330.4^{\circ}$ and a positive A_1 command gives rise to a maximum blade angle at $\psi = 240.4^{\circ}$.

Classical helicopter rotation defines cyclic pitch inputs by the law

$$\Delta\theta = -A_1 \cos \psi - B_1 \sin \psi$$

For this test the cyclic blade angle is defined as

$$\Delta\theta = - A_{1}_{TEST} \cos (\psi - 60.4) - B_{1}_{TEST} \sin (\psi - 60.4)$$

The transformation of test cyclics to classical axis is thus

$$\begin{bmatrix} A_1 \\ B_1 \end{bmatrix} = \begin{bmatrix} .4939 & , & - .8696 \\ .8696 & , & .4939 \end{bmatrix} \begin{bmatrix} A_1 & TEST \\ B_1 & TEST \end{bmatrix}$$

The data presented in this document and the Appendix volumes (References 4 , 5 and 6) are given in terms of test cyclic axes unless otherwise noted.

The instrumentation used on the model included three six component strain gage balances, one in each nacelle to measure rotor hub forces and moments and one total aircraft balance. The positions of the balances in relation to each other and with respect to the hub centers and aircraft reference CG locations are shown in figure 34. The nacelle balances were calibrated about the hub center, and the total loads balance about the reference CG.

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FIGURE

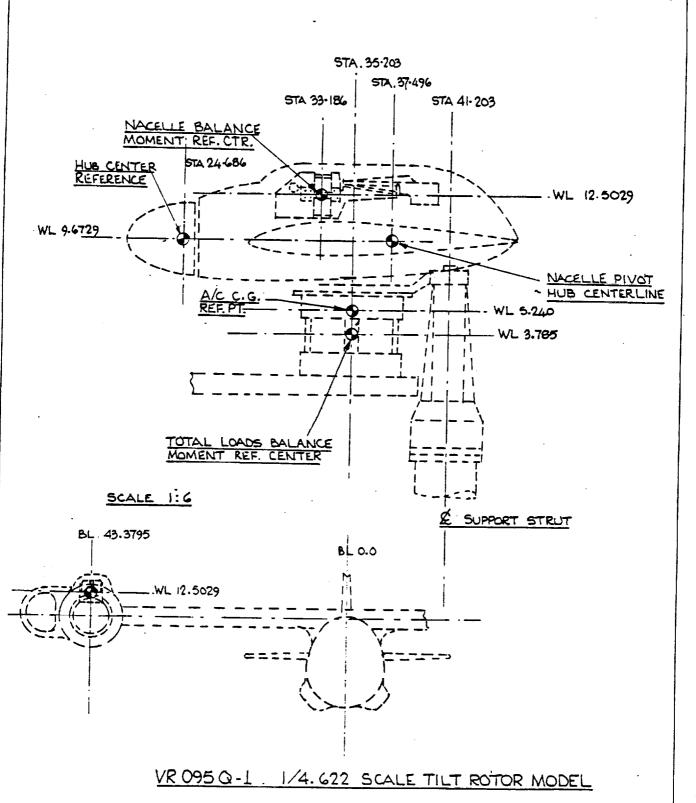


Figure 34. RELATIVE BALANCE LOCATIONS & MODEL REFERENCES

KEF 6/2/76 FORM 48284 (2/86) In addition to the strain gage balances, the blades were instrumented to provide chord and flap bending at 0.125R and also pitchlink loads and the rotor RPM and 1/rev signals were also generated. The blade positions when the 1/rev market fires are shown in figure 35.

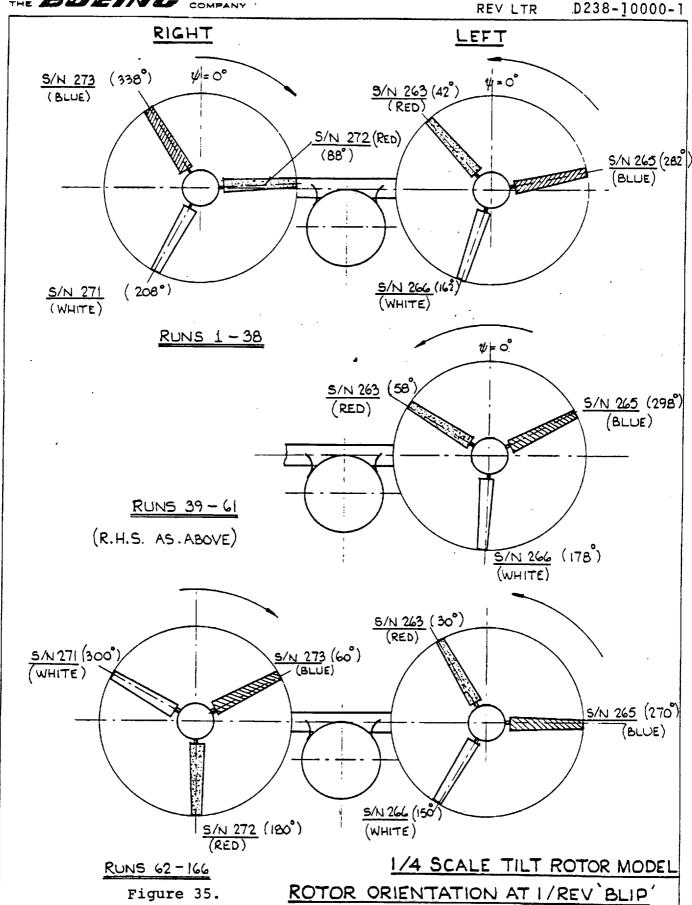
The rotor power was obtained from strain gages on the rotor shaft aligned to measure torque.

The positions of the collective and cyclic controls, wing flap setting and nacelle incidence were obtained from the appropriate control channel follow up potentiometer and provided as analogue and digital displays and inputs made to the data reduction computer on line.

Thermocouples were used to provide safety monitoring of critical motor, gearbox and cross shaft bearing temperatures. Three accelerometers were also mounted in each nacelle and used to monitor the aeroelastic stability of the wing modes.

All of the primary instrumentation channels were available on a patch panel such that any channel could be patched to a digital volt meter and a spectral analyzer on line. This instrumentation enabled the stability of the aeroelastic modes to be monitored and in some instances provided appropriate diagnostic information for model problem resolution on test.

The rotors used on the model were 85.72 cm (33.75 ins) radius and were a soft inplane hingeless rotor configuration having



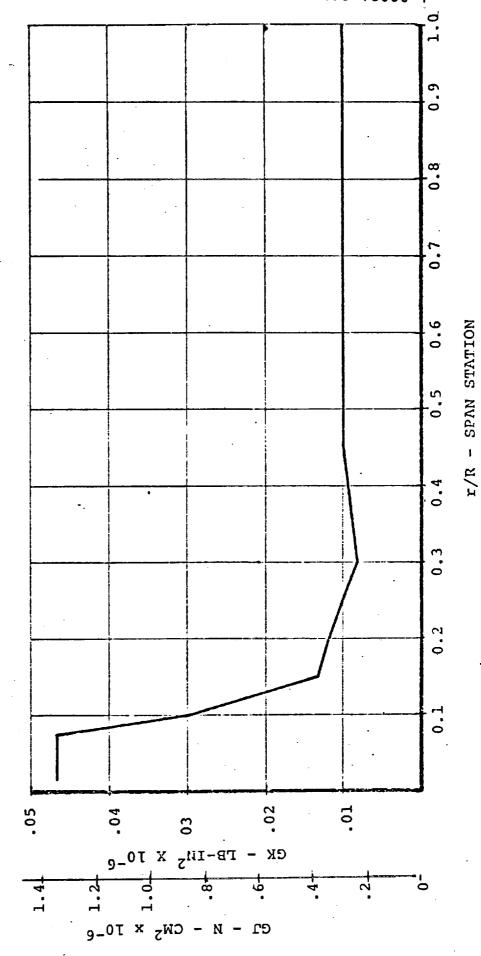
three blades and a solidity of 0.115. The aeroelastic properties of the blades were scaled from the 7.9 m (26 ft.) diameter rotor designed, built and tested under NASA Contract NAS2-6505.

The properties of the model rotor blades are shown in figures 36 to 44.

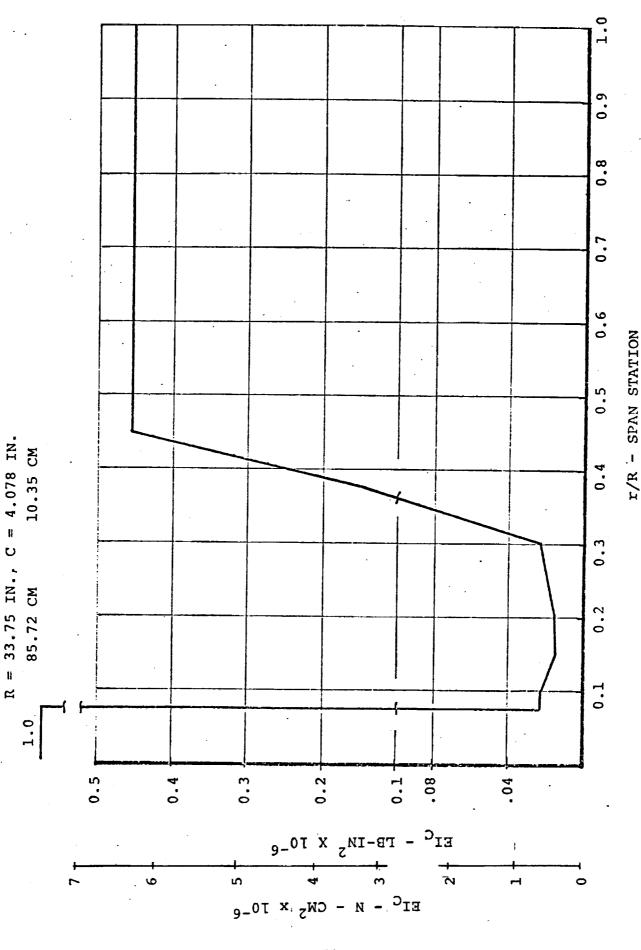
r/R - SPAN STATION

9.0 0.7 FROUDE SCALE MODEL 222 PITCHING INERTIA DISTRIBUTION R = 33.75 IN., C = 4.078 IN., P.A. = .952 IN.2.41 CM 9.0 0.5 10.35 CM 85.72 CM .04 .16 FIGURE 36. .24 .20. 9 I 80. re-In2/In. CM N/CM .04 I0 √Kå -58

FIGURE 37. FROUDE SCALE MODEL 222 TORSIONAL STIFFNESS DISTRIBUTION

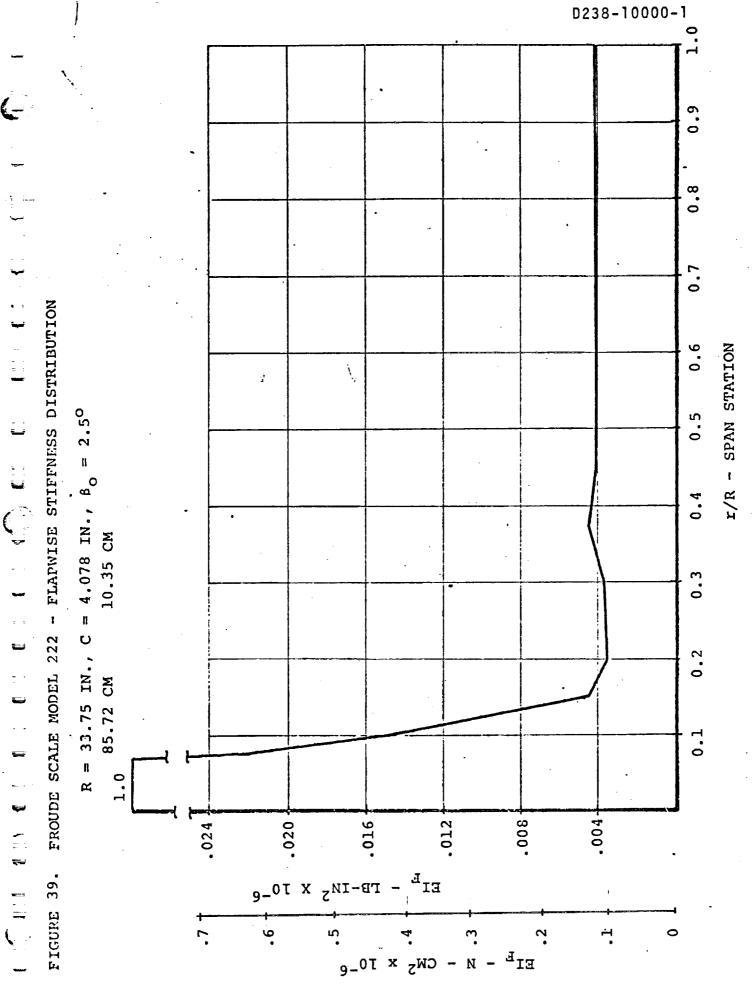


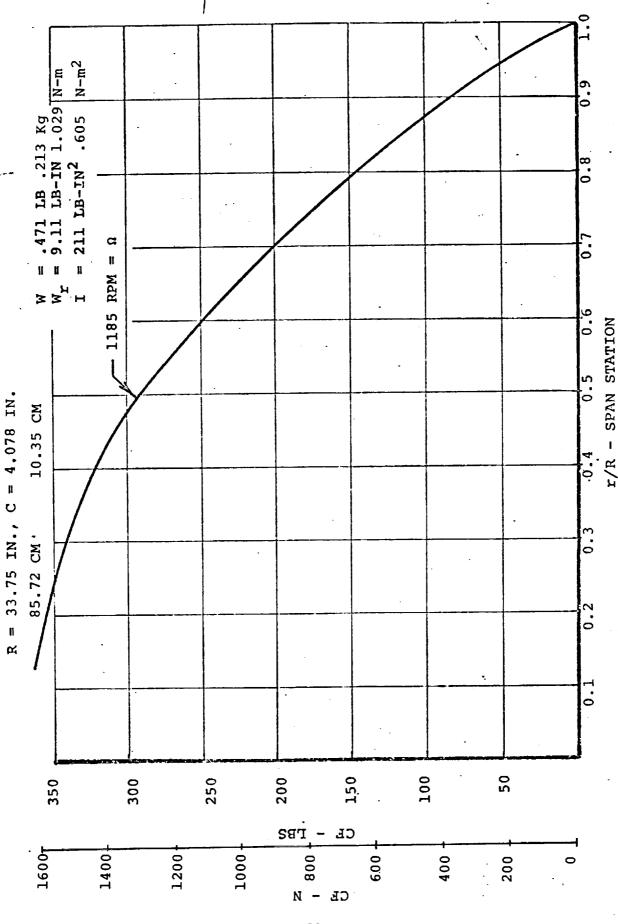
I



FROUDE SCALE MODEL 222 CHORDWISE STIFFNESS DISTRIBUTION

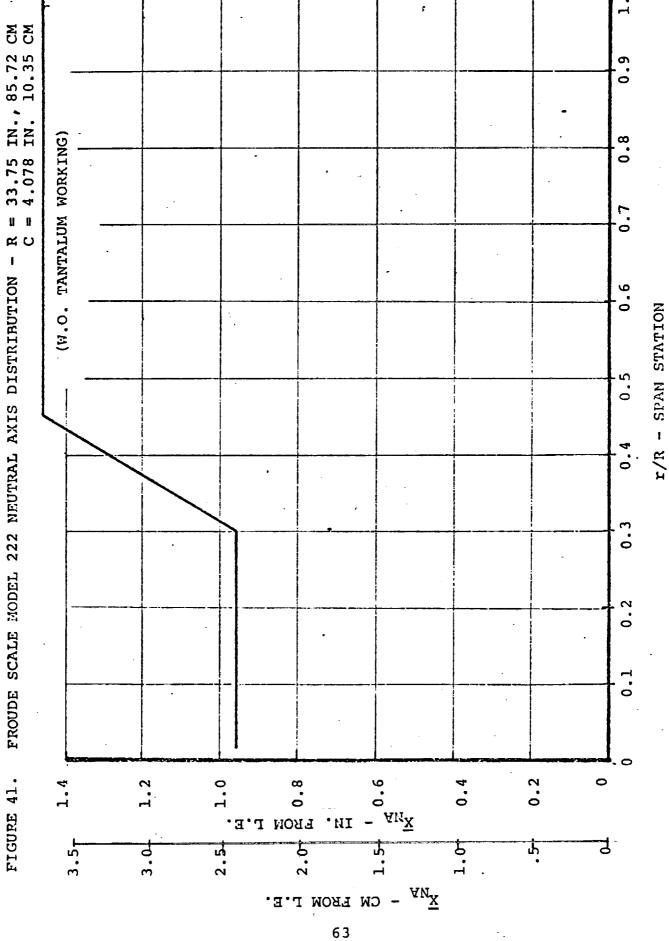
FIGURE 38.



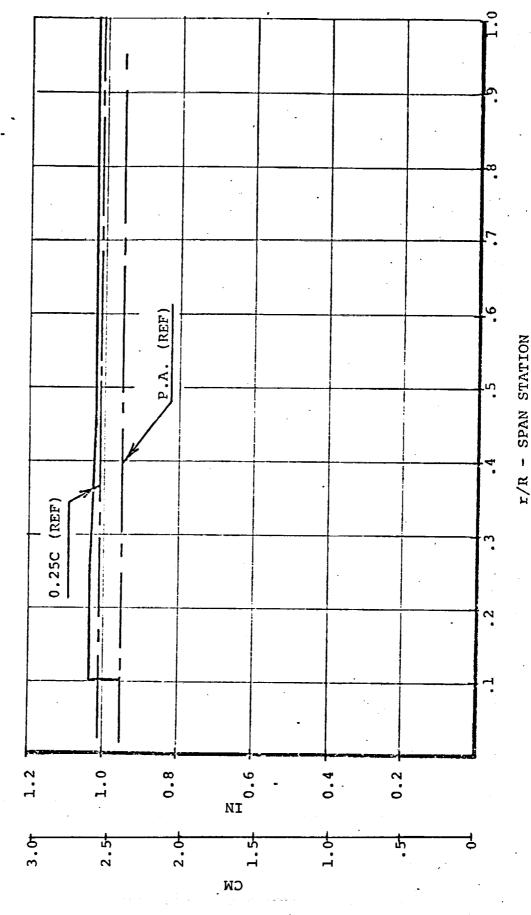


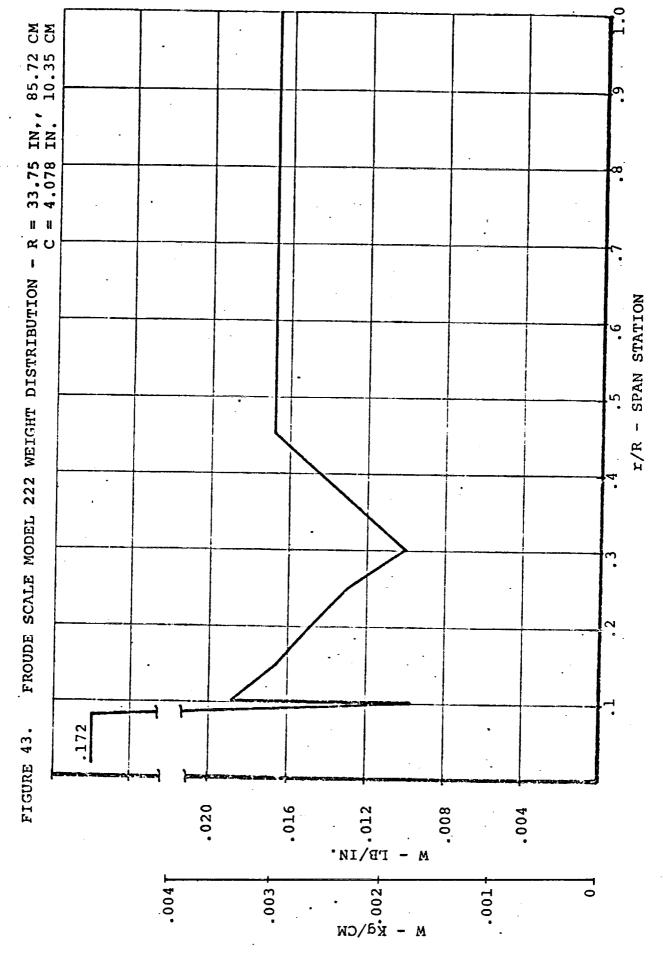
FROUDE SCALE MODEL 222 CENTRIFUGAL FORCE DISTRIBUTION

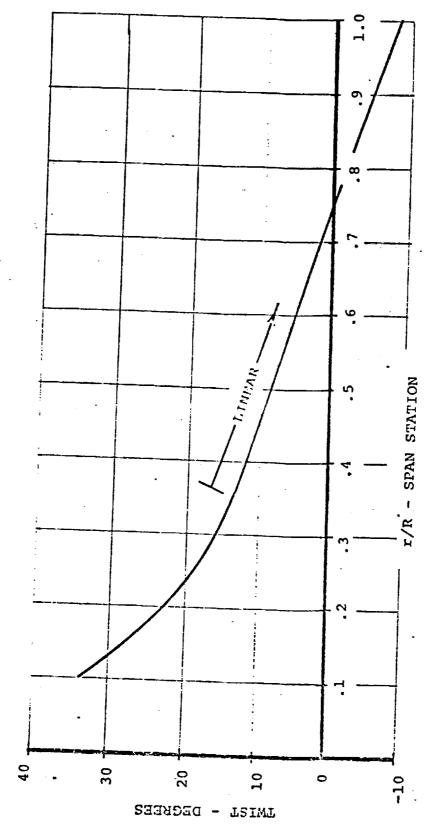
FIGURE 40.



FROUDE SCALE MODEL 222 CENTROIDAL AXIS DISTRIBUTION FIGURE 42.







. 85.72 CM 10.35 CM

FROUDE SCALE MODEL 222 TWIST DISTRIBUTION

FIGURE 44.

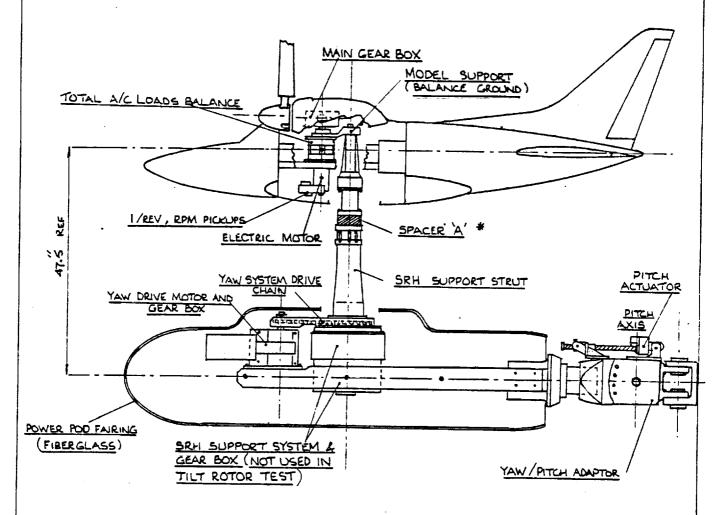
3.2 Model Installation and Wind Tunnel Data

The model was mounted in the wind tunnel on the SRH test stand which itself mounts on the wind tunnel sting. The test stand provides for remote actuation of pitch and yaw attitudes of the model and is shown in figure 45. The model was mounted on a pedestal support from the test stand.

The test stand usually incorporates a six component balance located where "Spacer A" is indicated. For the first 26 test runs this was replaced by a dummy balance since a total loads balance exists in the model. Ground resonance difficulties were observed and deduced to be due to the coalescence of the lower blade lag mode and the total loads balance pitch axis flexure frequency. The model balance was locked out by a stiffener and the spacer replaced by the SRH balance in order to measure loads. Further difficulties were encountered and eventually determined to be the fore and aft motion of the vertical pedestal whose frequency was similar to the original pitch axis frequency. These problems were eventually solved by removing the SRH balance and shortening the vertical pedestal thus increasing the frequency of the mode. The model total loads balance lock was removed and lead weights added to the fuselage nose and tail internally. Sufficient increase in pitch inertia was obtained to decrease the model balance pitch mode frequency and provide a stable mode. This configuration was used for the remainder of the test program.

FIGURE 1

* FOR RUNS 1-26 SPACER A' WAS 20" LONG (DUMMY SRH BALANCE). FOR RUNS 27-35 SPACER REPLACED BY SRH BALANCE (20" LONG). FOR RUNS 36-166 SPACER 'A' FITTED AS DRAWN (2" LONG).



SCALE : 1/20

VR 095Q-1 ~ 1/4.622 SCALE TILT ROTOR MODEL

Figure 45. CENERAL ARRANGEMENT AND INSTALLATION ON SRH TEST STAND

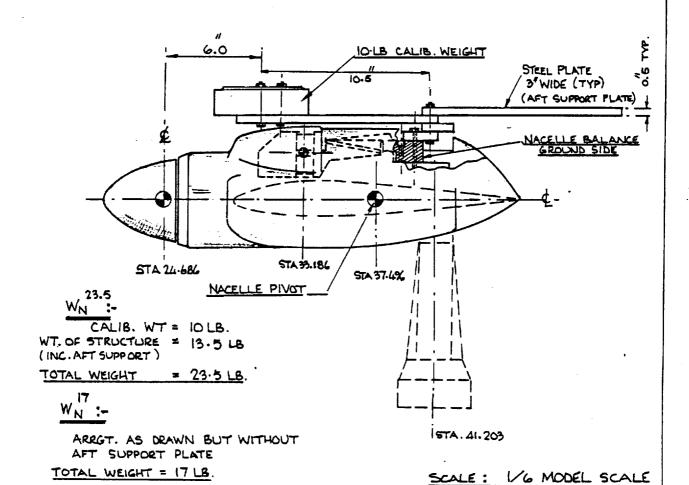
FORM 46284 (2/66)

No instabilities were encountered for the duration of the test; however, it became apparent that the model wing/wing-nacelle pitch frequency was close to 1/rev in cruise conditions and was lower than anticipated. This was thought to be due to the stiffness of the nacelle/wing interface since stiffening the wing and the nacelle balance had little or no effect. The structure of the interface is fairly complex and did not provide an easy means of stiffening so it was decided to increase the inertia and drop the frequency to avoid incorrect amplification of the rotor loads in cruise due to hub motion. This was felt to be an acceptable solution since aeroelastic considerations did not enter into the test objectives. Details of the weight added are shown in Figure 46.

Throughout the test the model was tested at the tunnel centerline.

The tunnel is a closed circuit, continuous flow facility and contains nine fixed-pitch blades, 11.9 m (39 feet) in diameter, which provide wind speeds up to 240 knots. The fan is powered by a 15,000 horsepower motor package consisting of two separate motors located in a nacelle. Air travels through the 226 m (742 foot) closed circuit tunnel and is turned by vanes into the test section which is 6 m (20 feet) wide, 6 m (20 feet) high and 13.7 m (45 feet) long. The tunnel is equipped with an air exchange system which reduces tunnel temperature and





VR 095 Q-1 1/4.622 SCALE TILT ROTOR

Figure 46. DETAILS OF TUNING WEIGHT ADDED TO NACELLES

KEF 6/9/2 FORM 46284 (2/66) also removes the turbulent air boundary layer before it enters the test section. New air is pulled into the wind tunnel through the inlet section of the air exchange system located downstream from the test section. Pertinent wind tunnel data are shown in Table 2 and the wind tunnel general arrangement is shown in figure 47.

TABLE 2. BOEING V/STOL WIND. TUNNEL PERTINENT DATA

CIRCUIT DIMENSIONS

105 m (347 feet) (approx. square in cross section) Length (overall) 36.5 m (120 feet) Width (overall)

Height (ground)

15.2 m (50 feet)

TEST SECTION DIMENSIONS

Closed 6 m (20 feet) square by 13.7 m (45 feet) long Slotted 6 m (20 feet) square by 13.7 m (45 feet) long; 10 percent porosity 6 m (20 feet) square by 7 m (23 feet) long Open Throat Contraction Ratio 6:1

Diffuser Angle

6 degrees equivalent cone (maximum)

FAN DESCRIPTION

Diameter 11.8 m (39 feet)

9, fixed pitch Blades

13,500 AC, 1,500 DC: 15,000 total Motors (horsepower) 5.5 m (18 feet) maximum diameter by 21.9 m Nacelle

(72 feet) long, 272 design rpm

MODEL SUPPORT SYSTEM

3.6 m (12 feet) by 4.8 m (16 feet) floor insert, Floor Mount custom installation

AUXILIARY SYSTEMS

Data Acquisition

120-channel system using an IBM 1800 computer which operates independently or linked to a central IBM 360 system

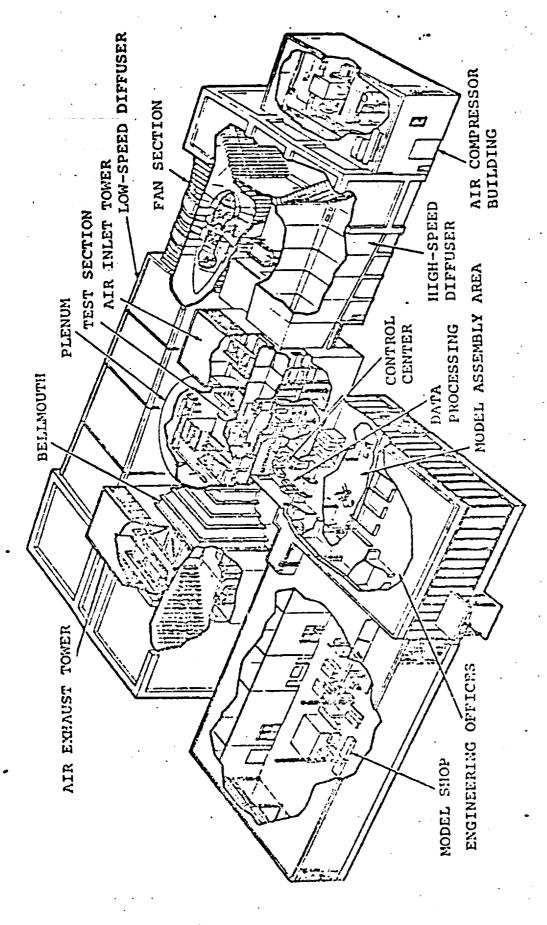


Figure 47. The Boeing V/STOL Wind Tunnel General Arrangement

3.3 Sign Conventions and Scale Factors

The sign conventions for forces and moments maintained throughout the test are depicted in figure 48. The rotor hub force
and moment convention is identical to the total loads balance
convention in the cruise condition shown. It should be noted
however that the rotor hub axes system and sign convention is
maintained relative to the rotor shaft axis at all values of
nacelle incidence.

For example, this means that rotor yaw moment is in the same sense as aircraft yaw moment at $I_N = 0^{\circ}$ but coincides with aircraft roll moment at $I_N = 90^{\circ}$. Similarly, rotor normal force at $I_N = 0^{\circ}$ is in the same sense as aircraft lift but as the nacelle incidence is increased to $I_N = 90^{\circ}$ the normal force acts in the same sense as aircraft drag.

Positive pitch and yaw attitudes are in the same sense as positive aircraft pitch and yaw moments.

The model is a 1/4.622 Froude scale model; therefore, the scale factors to be used in converting from model to full scale are as given below.

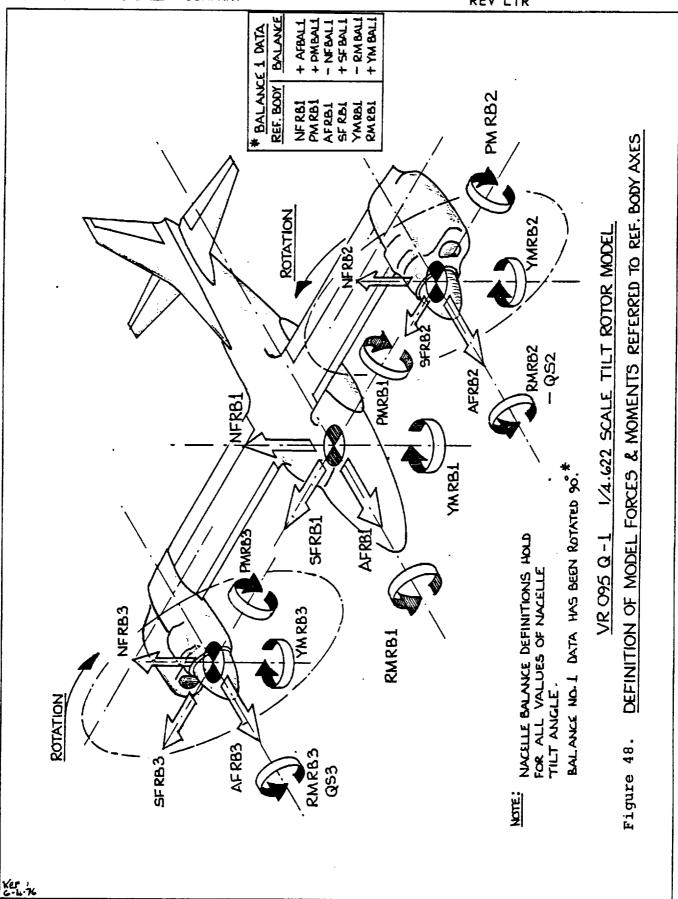
	Scale Factor
Linear dimensions	4.622
Mass or weight	98.739
Time	2.15
Frequency	0.46514

	Scale Factor
Velocity	2.15
Viscous Damping	45.927
Stiffness	2109.36
Spring rate	21.363
Mass Moment of Inertia	2109.36
Force	98.739
Strain	1.0
Moment or Torque	456.373
Power	212:278
Per rev frequency	1.0
Disc loading	4.622
Mach No.	2.1498
Froude No.	1.0
Lock No.	1.0

Companions of model and full scale blade Mach No. and Re. No. in hover are shown in figures 49 and 50.

3

FORM 46284 (2/66)



SHEET 76

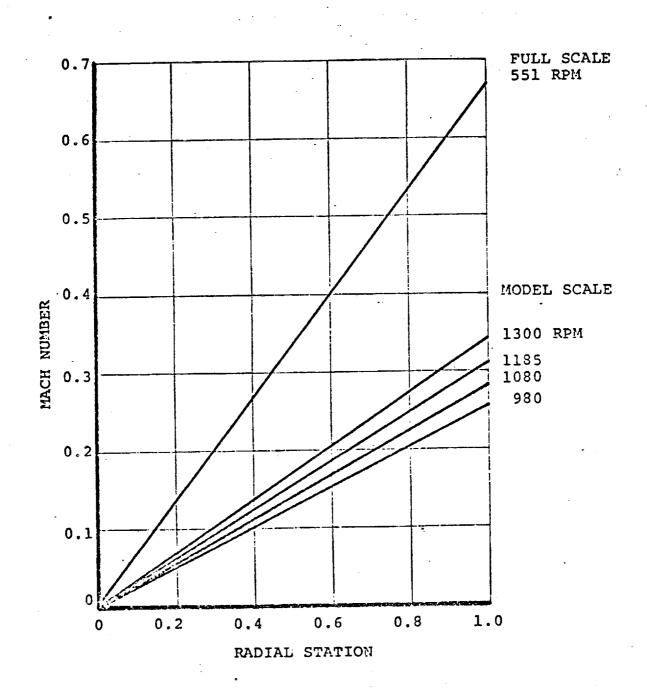


FIGURE 49. COMPARISON OF MODEL SCALE AND FULL SCALE BLADE MACH NUMBER DISTRIBUTIONS.

....

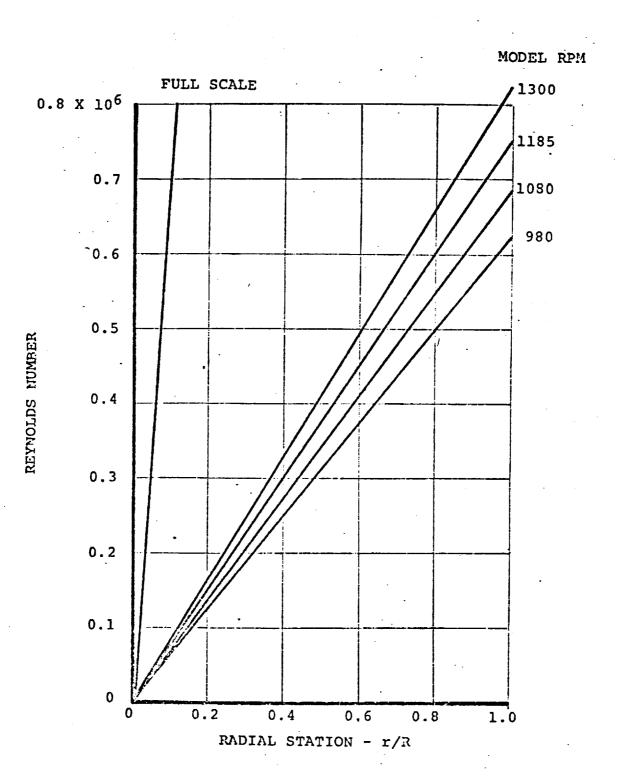


FIGURE 50. COMPARISON OF MODEL SCALE AND FULL SCALE REYNOLDS NUMBER DISTRIBUTIONS.

3.4 Data Reduction

ta i

In the early stages of the test a series of runs were made with no blades corresponding to the nacelle incidences, attitudes, RPM's and velocities to be used during the blades on testing. The forces and moments measured on the nacelle balances were divided by dynamic pressure and curve fitted to form the basic hub and spinner tares.

Data taken on the nacelle balances was processed through the balance matrix and corrected for the appropriate hub and spinner tares previously measured at the same operating conditions.

In order to provide an accurate accounting for the rotor shaft incidence the elastic deflections of the model were also used to compute the rotor incidence. This was done by using prior measurements of pitch deflection due to hub moment and normal force.

The summary of the data reduction program is on file at the wind tunnel for BVWT 105. The critical dimensions used as input data for this program are presented in table 3 and a sketch of the balance arrangement is shown in figure 34.

To account for model flexibility in the pitch direction the equations presented below are integrated in the data reduction program.

Wing Pitch Deflections

Nacelle Pitch Deflections

$$\Delta \alpha i_{N2} = (K3=K4\cos i_{N2}) NF2RD+K5PM2RB$$

$$-K6T2RB \cos i_{N2} + \Delta \alpha w_{1}$$

$$\Delta \alpha i_{N3} = (K3-K4 \cos i_{N3}) NF3RB+K5PM3RB$$

$$-K6T3RB \cos i_{N3} + \Delta \alpha w_{1}$$

$$i_{N2} \cot r = i_{N2} + \Delta \alpha i_{N2}$$

$$i_{N3} \cot r = i_{N3} + \Delta \alpha i_{N3}$$

 K_1 = wing rotation due to pitching moment applied by the wing K_2 = wing rotation due to pitching moment applied by the rotor K_3 = rotor disc rotation due to rotor normal force

The information is thus reduced and printed. Copies of the computer printout results from which the plotted data were made were given to the NASA technical monitor in microfiche form.

Table 4 defines the nomenclature used by the data reduction program.

TABLE	3.	-	WIND	TUNNEL	DATA	REDUCTION	TNPHT	COMSTANTS
	~ .		"		Unin	ALDUC, LICH	LINELLI	L CONTRACTOR

			7		MENSIONS PRINT
RD	INC	SYM		UNITS	
	1	× ₂	Horiz. Dist. from Left Nacelle Bal. Axis & to Ref. Body Axis	FT	.7083
	2	У2	Lat. Dist. from Left Nacelle Bal. Axis £ to Ref. Eody Axis	FT	. 0.0
	3	^z 2	Vert. Dist. from Left Nacelle Bal. Axis C to Ref. Body Axis	FT	2188
	4	x ₃	Horiz. Dist. from Right Nacelle Bal. Axis & to Ref. Body Axis	FT	.7083
	5	У ₃	Lat. Dist. from Right Nacelle Bal. Axis & to Ref. Body Axis	FT	0.0
-	6	z 3	Vert. Dist. from Right Nacelle Bal. Axis & to Ref. Body Axis	FT	2188
	7	d ₂	Left Torque Directional Sign i.e. as CW Rotation (Blade) =-1 view from	1	-1
	8	d ₃	Right Torque Directional Sign i.e.pilot CCW Rotation (Blade) =+1 seat		+1 ،
•	9	12	Horiz. Dist. from Left Nacelle Ref. Body Axis to Nacelle Pivot Point	FT -	-1.0729
1	.0	^m 2	Lat. Dist. from Left Nacelle Ref. Body Axis to Nacelle Pivot Point	FT	0.0
1	.1	n ₂	Vert. Dist. from Left Nacelle Ref. Body Axis to Nacelle Pivot Point	FT	0.0
1	.2	13	Horiz. Dist. from Right Nacelle Ref. Axis to Nacelle Pivot Point	FT	-1.0729
1	.3	^m 3	Lat. Dist. from Right Nacelle Ref. Body Axis to Nacelle Pivot Point	. FT	0.0
1	.4	n ₃	Vert. Dist. from Right Nacelle Ref. Body Axis to Nacelle Pivot Point	FT	0.0
1	.5	el	Horiz. Dist. from Aircraft Balance Axis ¢ to Model Body Axis	FT	0.0
1	.6.	fl	Lat. Dist. from Aircraft Balance Axis to Model Body Axis	ΕĀ	0.0
<u> </u>				<u> </u>	

TABLE 3.

INPUT CONSTANTS (continued)

ALL	DIM	MENSIONS	
F	PER	PRINT	

	•	÷	PER F	RINT
RDINC	SYM		UNITS	
17	g ₁	Vert. Dist. from Aircraft Balance Axis & to Model Body Axis	FT	.3908
18	e ₂	Horiz. Dist. from Left Nacelle Pivot Axis to Model Body Axis	FT	+.1911
19	f ₂	Lat. Dist. from Left Nacelle Pivot Axis to Model Body Axis (neglecting droop and/or bent spar)	FT -	+3.6150
20	g ₂	Vert. Dis. from Left Nacelle Pivot Axis to Model Body Axis	FT	0794
21	e ₃	Horiz. Dist. from Right Nacelle Pivot Axis to Model Body Axis	FT	+.1911
22	f ₃	Lat. Dist. from Right Nacelle Pivot Axis to Model Body Axis (neglecting droop and/or best spar)	FT	-3.6150
23	93	Vert. Dist. from Right Nacelle Pivot Axis to Model Body Axis	FT	0794
24	S	Wing Area	FT ²	9.360
25	b	Wing Span	FT	7.230
26	c '	Wing Chord	FT	1.294
27	R ₂	Left Rotor Radius	FT	2.8125
28	R ₃	Right Rotor Radius	FT	2.8125
-		•		
	,	-		
-	•	_		-
2.0				



Table 4.

LIST AND DEFINITION OF PRINTOUT PARAMETERS

1. TUNNEL PARAMETERS

VTUN	Tunnel	Velocity	ft/sec		
PTOTAL	Tunnel	Total Pressure	lb/ft ²		
PSTATIC	Tunnel	Static Pressure	lb/ft ²		
RHOTUN	Tunnel	Air Density	slug/ft ³	(1b	sec^2/ft^4)
TSTATIC	Tunnel	Temperature	°F		
OTUN	Tunnel	Dynamic Pressure	lb/ft ²		

2. BALANCE PARAMETERS

2.1 General

= 7

NF	Normal Force	lb.
PM	Pitching Moment	ft. lb.
AF	Axial Force	lb.
SF	Side Force	lb.
YM	Yawing Moment	ft. lb.
RM	Rolling Moment	ft. lb.
	Torque	ft. lb.

2.2 Balance Parameters, Interactions, Weight Tares Applied Torque Corrections Applied

Fuselage (Total Loads) Balance	<u>Left Nacelle</u> <u>Balance</u>	Right Nacelle Balance
NFBALl	NFBAL2	NFBAL3
PMBALl	PMBAL2	PMBAL3
AFBAL1	AFBAL2	AFBAL3
SFBAL1	SFBAL2	SFBAL3
YMBALl	YMBAL2	YMBAL3
RMBAL1	RMBAL2	RMBAL3

2.3 Nacelle Balance Data Transferred to Rotor Reference Body Axes

NFRB2R Left rotor normal force, perpendicular to hub axis PMRB2R Left rotor pitching moment about hub ref. point (ϕ) TRB2R Left rotor thrust, along hub axis

2.3 <u>Nacelle Balance Data Transferred to Rotor Reference</u> <u>Body Axes</u> (Cont'd)

SFRB2R Left rotor side force, perpendicular to hub axis

YMRB2R Left rotor yawing moment about hub ref. point (¢) (plane perpendicular to NFRB2R)

RMRB2R Left rotor rolling moment about hub ref. point (¢) (plane perpendicular to TRB2R)

QRB2R Left rotor shaft torque

NFRB3R Right rotor normal force, perpendicular to hub axis

etc. etc.

2.4 Nacelle Balance Data Rotor Ref. Body Axes, Corrected for Hub Tares

NFRB2B Left rotor normal force, perp. to hub axis, corr. for hub tares

PMRB2B Left rotor pitching moment about hub ref., corr. for hub tares

TRB2B Left rotor thrust along hub axis, corr. for hub tares

SFRB2B Left rotor side force, perp. to hub axis, corr. for hub tares

YMRB2B Left rotor yawing moment about hub ref. corr. for hub tares

RMRB2B Left rotor rolling moment about hub ref. corr. for hub tares

QRB2B Left rotor torque corrected for hub tares

NFRB3B Right rotor normal force, perp. to hub axis, corr. for hub tares

etc. etc.

2.5 Nacelle Balance Data Referred to Model Body Axes, Hub Tares Not Removed

NFMB-L Left rotor normal force, model body axes

PMMB-L Left rotor pitching moment about body ref. point (A/C C.G.)

AFMB-L Left rotor axial force, model body axes (+ fwd)

SFMB-L Left rotor side force, model body axes

YMMB-L Left rotor yawing moment about body ref. point (A/C C.G.)

2.5 <u>Nacelle Balance Data Referred to Model Body Axes, Hub Tares</u> <u>Not Removed</u> (Cont'd)

RMMB-L Left rotor rolling moment about body ref. point (A/C C.G.)

NFMB-R Right rotor normal force, model body axes etc.

2.6 Fuselage Balance (Total Loads) Transferred to Model Body Axes

NFMB-AC Total aircraft normal force, body axes

PMMB-AC Total aircraft pitching moment ref. to A/C C.G.

AFMB-AC Total aircraft axial force, body axes (+ fwd)

SFMB-AC Total aircraft sideforce, body axes

YMMB-AC Total aircraft yawing moment, ref. to A/C C.G.

RMMB-AC Total aircraft rolling moment, ref. to A/C C.G.

2.7 Airframe Data Model Body Axes (Corrected for Rotor Effects)

NFMB-AF Airframe normal force, body axes

PMMB-AF Airframe pitching moment ref. to A/C C.G.

DMB -AF Airframe drag, body axes, positive aft

SFMB-AF Airframe sideforce, body axes

YMMB-AF Airframe yawing moment, ref. to A/C C.G.

RMMB-AF Airframe rolling moment, ref. to A/C C.G.

2.8 Fuselage Balance (Total A/C Loads) Transferred to Wind Axes

LW -AC Total aircraft lift, wind axes

PMW-AC Total aircraft pitching moment, ref. to A/C C.G.

AFW-AC Total aircraft axial force, wind axes, positive fwd

SFW-AC Total aircraft sideforce, wind axes

YMW-AC Total aircraft yawing moment, ref. to A/C C.G.

RMW-AC Total aircraft rolling moment, ref. to A/C C.G.

2.9 Airframe Data Wind Axes (Corrected for Rotor Effects)

LW-AF Airframe lift, wind axes

PMW-AF Airframe pitching moment ref. to A/C C.G.

DW-AF Airframe drag, wind axes, positive aft

SFW-AF Airframe side force, wind axes

YMW-AF Airframe yawing moment, ref. to A/C C.G.

RMW-AF Airframe rolling moment, ref. to A/C C.G.

3. NON DIMENSIONAL COEFFICIENTS

3.1 Aircraft

3.1.1 Model Body Axis Coefficients

```
CNFMB-AC = NFMB-AC / QTUN·S

CPMMB-AC = PMMB-AC / QTUN·S·C

CAFMB-AC = AFMB-AC / QTUN·S

CSFMB-AC = SFMB-AC / QTUN·S·B

CYMMB-AC = YMMB-AC / QTUN·S·B

CRMMB-AC = RMMB-AC / QTUN·S·B
```

3.1.2 Wind Axis Coefficients

```
CLW-AC = LW-AC / QTUN·S

CPMW-AC = PMW-AC / QTUN·S·C

CAFW-AC = AFW-AC / QTUN·S

CSFW-AC = SFW-AC / QTUN·S·B

CYMW-AC = YMW-AC / QTUN·S·B

CRMW-AC = RMW-AC / QTUN·S·B
```

3.1.3 Model Body Axis Coefficients (Hover Option)

```
CNF1-HOV = NFMB-AC / 2\pi RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>

CPM1-HOV = PMMB-AC / 2\pi RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>

CAF1-HOV = AFMB-AC / 2\pi RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>

CSF1-HOV = SFMB-AC / 2\pi RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>

CYM1-HOV = YMMB-AC / 2\pi RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>

CRM1-HOV = RMMB-AC / 2\pi RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>
```

3.2 Airframe

3.2.1 Model Body Axis Coefficients

```
CNFMB-AF = NFMB-AF / QTUN·S·C
CPMMB-AF = PMMP-AF / QTUN·S·C
CDMB-AF = DMB-AF / QTUN·S
CSFMB-AF = SFMB-AF / QTUN·S·B
CYMMB-AF = YMMB-AF / QTUN·S·B
CRMMB-AF = RMMB-AF / QTUN·S·B
```

3.2.2 Wind Axis Coefficients

```
CLW-AF = LW-AF / QTUN·S

CPMW-AF = PMW-AF / QTUN·S·C

CDW-AF = DW-AF / QTUN·S

CSFW-AF = SFW-AF / QTUN·S·B

CYMW-AF = YMW-AF / QTUN·S·B

CRMW-AF = RMW-AF / QTUN·S·B
```

3.3 Rotors

1.7

3.3.1 Reference Body Axes

```
CNFR-L = NFRB2R / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· \pi

CPMR-L = PMRB2R / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· \pi

CTR-L = TRB2R / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· \pi

CSFR-L = SFRB2R / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· \pi

CYMR-L = YMRB2R / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· \pi

CRMR-L = RMRB2R / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· \pi

CPR-L = QRB2R / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· \pi

CNFR-R = NFRB3R / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· \pi

etc. etc.
```

Reference Body Axes, Hub Tares Removed

```
CNFB-L = NFRB2B / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· π

CPMB-L = PMRB2B / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· π

CTB-L = TRB2B / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· π

CSFB-L = SFRB2B / RHOTUN·R2<sup>2</sup>· (VTIP-L)<sup>2</sup>· π

CYMB-L = YMRB2B / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· π

CRMB-L = RMRB2B / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· π

CPB-L = QRB2B / RHOTUN·R2<sup>3</sup>· (VTIP-L)<sup>2</sup>· π

CNFB-R = NFRB3B / RHOTUN·R3<sup>2</sup>· (VTIP-R)<sup>2</sup>· π

etc. etc.
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E 7

4. GENERAL

OMEGA2 Rotational speed, left rotor = π RPM1 / 30 OMEGA3 Rotational speed, right rotor = π RPM2 / 30

VTIP-L Tip speed, left rotor = TRPM1·R2·/ 30 VTIP-R Tip speed, right rotor = TRPM2·R3·/ 30

MU-LEFT Advance ratio, left = VTUN / VTIP-L MU-RIGHT Advance ratio, right = VTUN / VTIP-R

V-KNOTS Tunnel speed, knots = 0.5921 VTUN V-FS Full scale speed, knots = 2.14988 V-KNOTS

5. ANGLES

ALPHAWIC Model angle of attack corrected for initial deflection and rotation due to airframe and rotor loading

ALPHAW2C Left nacelle incidence (relative to wind axis) corrected for initial deflection and rotation due to rotor loads

ALPHAW3C Right nacelle incidence (relative to wind axis) corrected for initial deflection and rotation due to rotor loads

NAC-2 Corrected left nacelle incidence, relative to body water line = ALPHAW2C-ALPHAW1C

NAC-3 Corrected right nacelle incidence relative to body water line = ALPHAW3C-ALPHAW1C

BETA Sideslip angle, positive nose to left.

6. CONTROL SYSTEM

COLL-L COLL-R	Collective pitch ($\theta_{.75}$ deg.) left rotor Collective pitch ($\theta_{.75}$ deg.) right rotor
AlC-LEFT AlC-RIGHT	Lateral cyclic pitch, control input, left Lateral cyclic pitch, control input, right
B1C-LEFT B1C-RIGHT	Longitudinal cyclic pitch, control input, left Longitudinal cyclic pitch, control input, right
Al-LEFT Al-RIGHT	Lateral cyclic pitch, pure input (#=90°), left Lateral cyclic pitch, pure input (#=90°), right
Bl-LEFT Bl-RIGHT	Longitudinal cyclic pitch, pure input (ψ =180°), left Longitudinal cyclic pitch, pure input (ψ =180°), right

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3.5 Frequency Data

The analysis and usage of data obtained on a hingeless rotor requires that the frequencies of the blades be known. The static blade frequencies were obtained by bang/tweak tests and the results are provided in table 5. The response of the blade gages at different RPM and collective pitch settings provide a signal input to the spectral analysis methodology and the on line ubiquitous analyzer used on test. This capability allowed us to check the rotating blade frequencies by identifying the peaks on response curves. An example is shown in figure 51.

The rotor blade rotating frequencies in hover at a collective pitch at 8° are shown in figure 52 and in the cruise configuration at a collective pitch of 34° in figure 53.

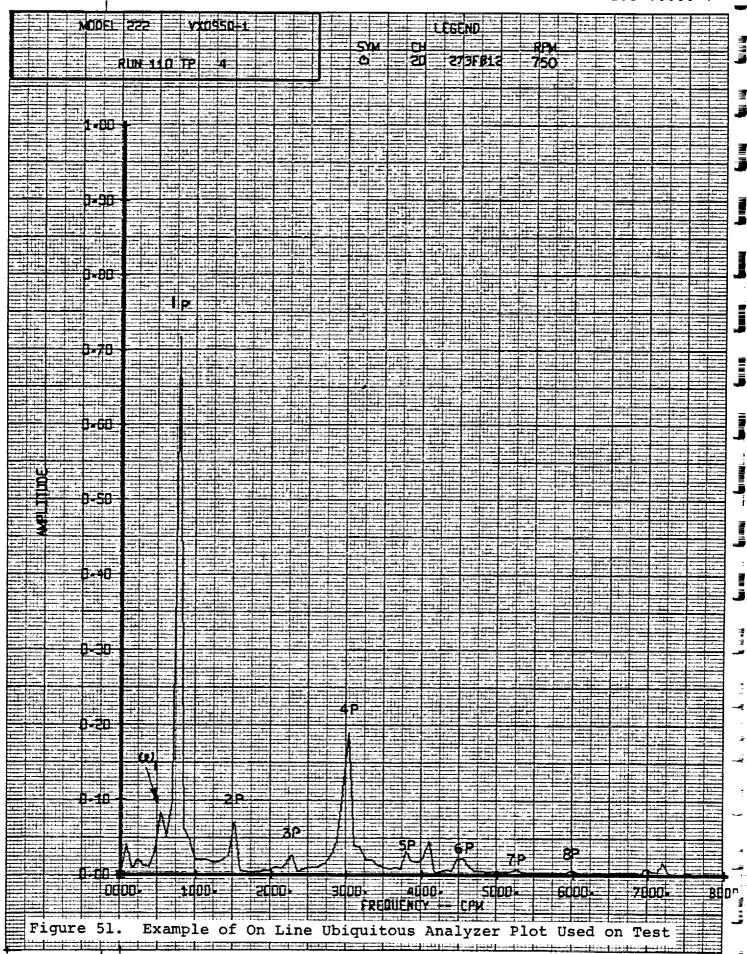
TABLE 5.

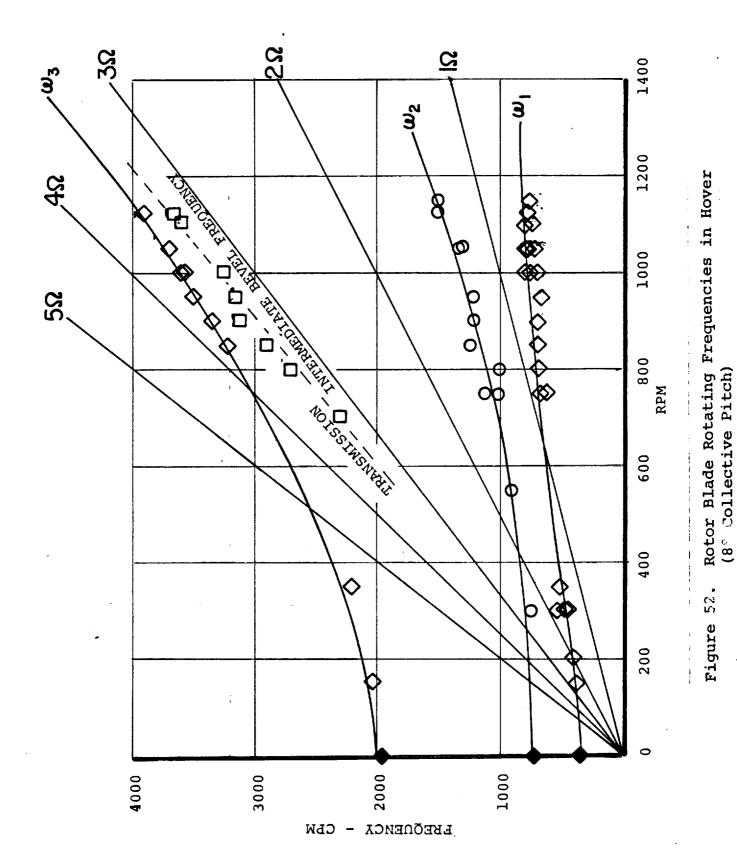
BLADE NATURAL FREQUENCIES FROM BANG/TWEAK TESTS

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265	5.52 5.60 5.53	5.76*	12.08 12.12 12.0	11.92* 11.83*	95.74 96.00 96.77	87.29 86.45 86.62		33.78 33.82
271	5.51 5.55 5.56	5.54 5.73* 5.86*	11.76 11.68 11.68	11.94 12.06* 12.00*		90.40 90.40	38.46 37.70 35.29	33.57 33.60
273	5.28 5.40 5.43	5.58*	11.92 12.00 11.92	12.03*	96.42	87.23 87.30 87.07	33.33 33.33 33.33	32.61 32.61

- ① Original values, blade cuffs fitted
- (2) Values measured with cuffs removed, 3/23/76

The test set-up was the same in both cases. An accelerometer was used to define the frequencies, except as defined thus * where a blade strain gauge output was used.





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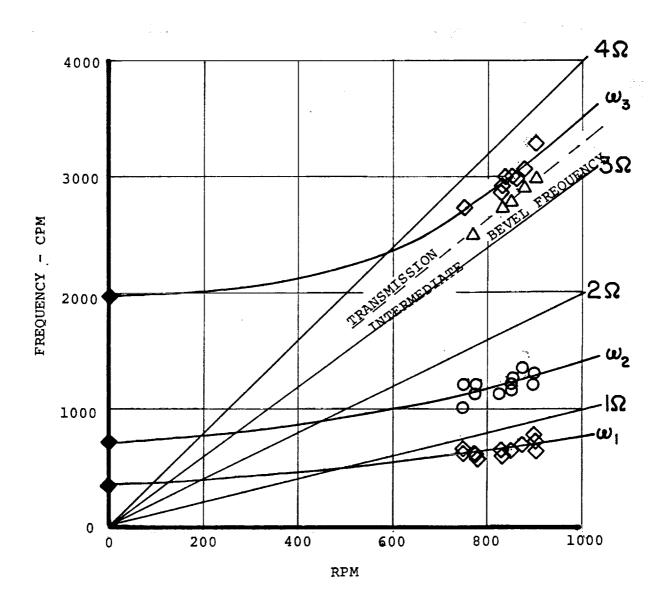


Figure 53. Rotor Blade Rotation Frequencies in Cruise (34° Collective Pitch)

4.0 SCOPE OF TEST AND TEST NOTES

The primary objective of the test program was to develop parametric force, moment and rotor loads data over the anticipated flight envelope of the tilt rotor aircraft. The scope of the test program is depicted in figure 54 which shows the seventeen initial test conditions used on test. These conditions were selected to provide an adequate coverage of the estimated flight envelope and to take advantage of existing full scale data obtained in the NASA Ames 40 x 80 wind tunnel (Reference 2) shown superimposed.

4.1 Test Program and Test Log

The procedure adopted for the data runs was to set up the model at one initial condition with an approximate trim attitude and cyclic pitch for minimum blade loads. From this initial condition the test variables were exercised in turn. In hover (condition 1) Figure 54, the model rotor performance was established, as well as cyclic pitch effectiveness at two thrust levels.

For each of the conditions in transition; i.e., conditions 2 through 12, a sequence of tests was run about each initial condition which involved varying angle of attack, yaw angle, longitudinal and lateral cyclic, collective pitch, wing flap setting and rotor RPM.

The cruise flight data, conditions 13 through 17, were obtained using a different sequence of tests. The nacelles were set to -1° and zero angle of attack and zero yaw established. The

INITIAL TEST CONDITIONS

Figure 54. Scope of Test, Initial Test Conditions

cyclic pitch settings were set to minimum loads. The aircraft angle of attack was varied with various wing flap settings establishing the α effects and providing data to determine the effect of wing C_L on the rotor derivatives. The effects of both axes of cyclic pitch were then established and finally α variations made with pre-calculated cyclic schedules and at conditions 13, 14, and 15, α variations with cyclic pitch tuned to minimum loads. These latter runs enable the "cyclic on the stick" data to be deduced.

The test log recorded during the program is provided as table

6. Runs 1 through 23 had no blades fitted and were performed to establish the hub tares required to establish the rotor data on later tests. Weight tares were established before each series of runs at a new configuration.

The test log defines the test configuration by a series of code letters which are summarized in table 7 and detailed explanation of the codes is given in table 8.

Table 6. 1/4 Scale Test Run Log

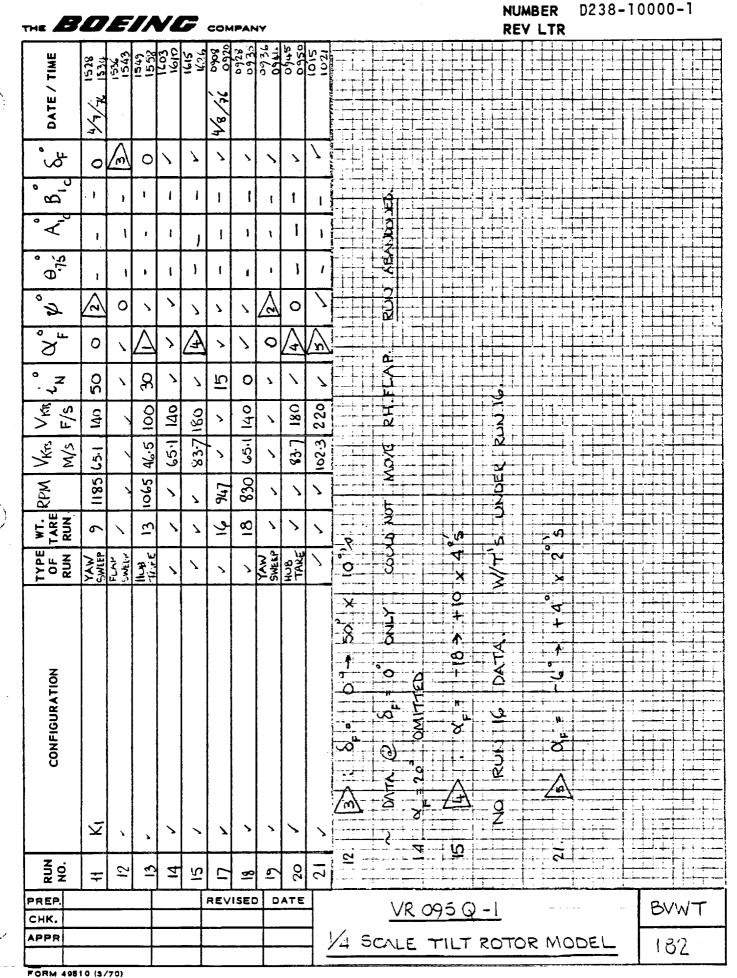
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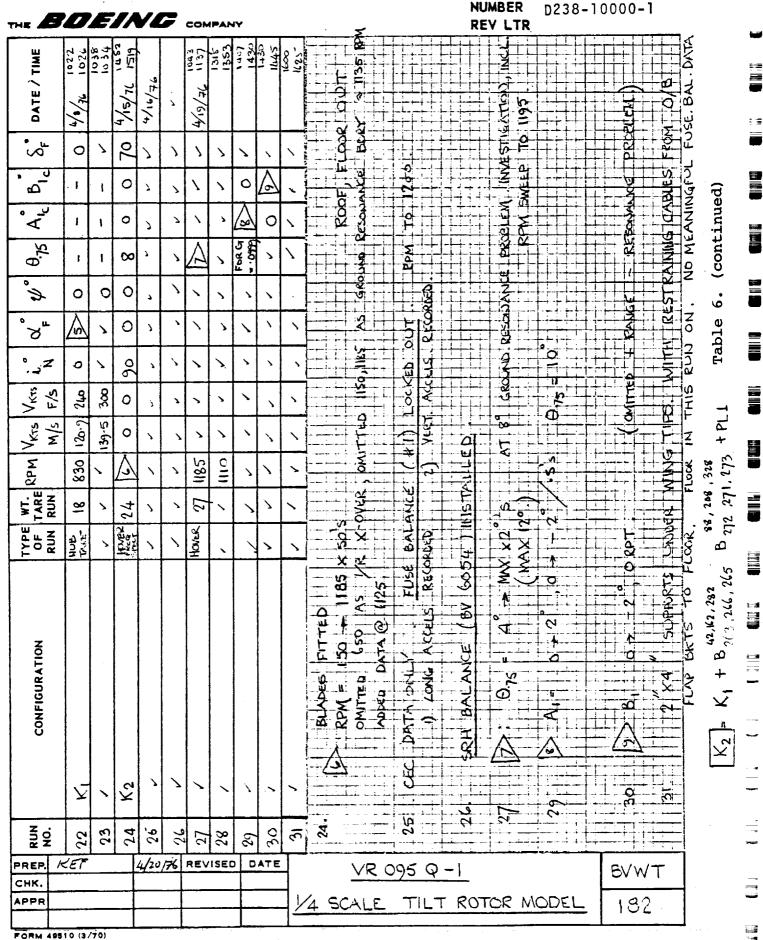
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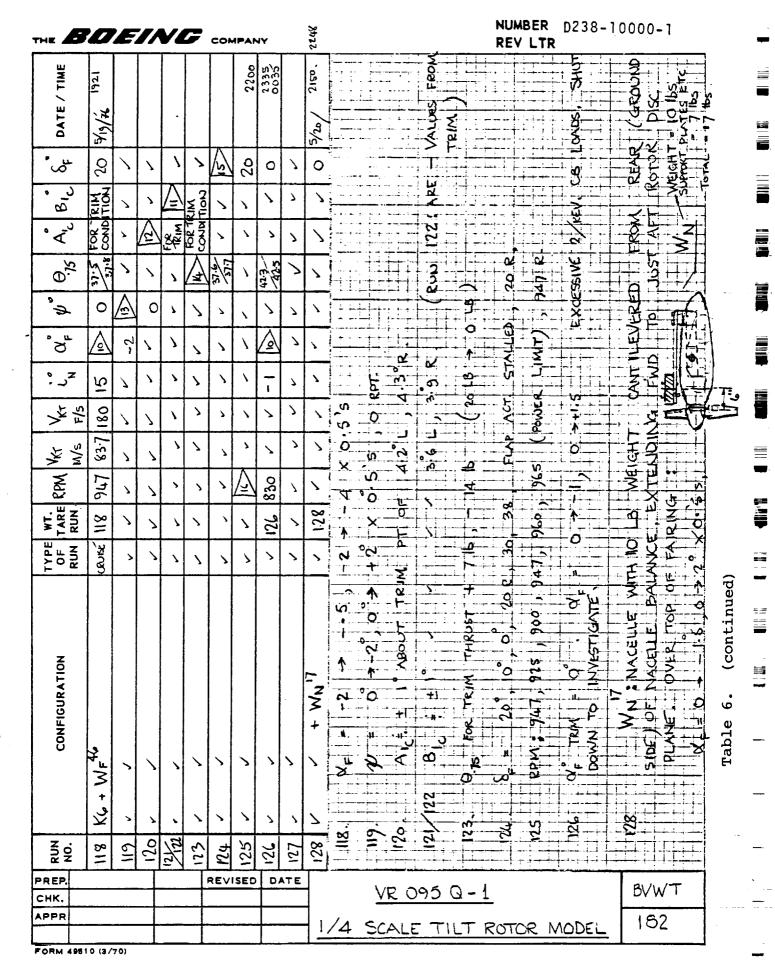
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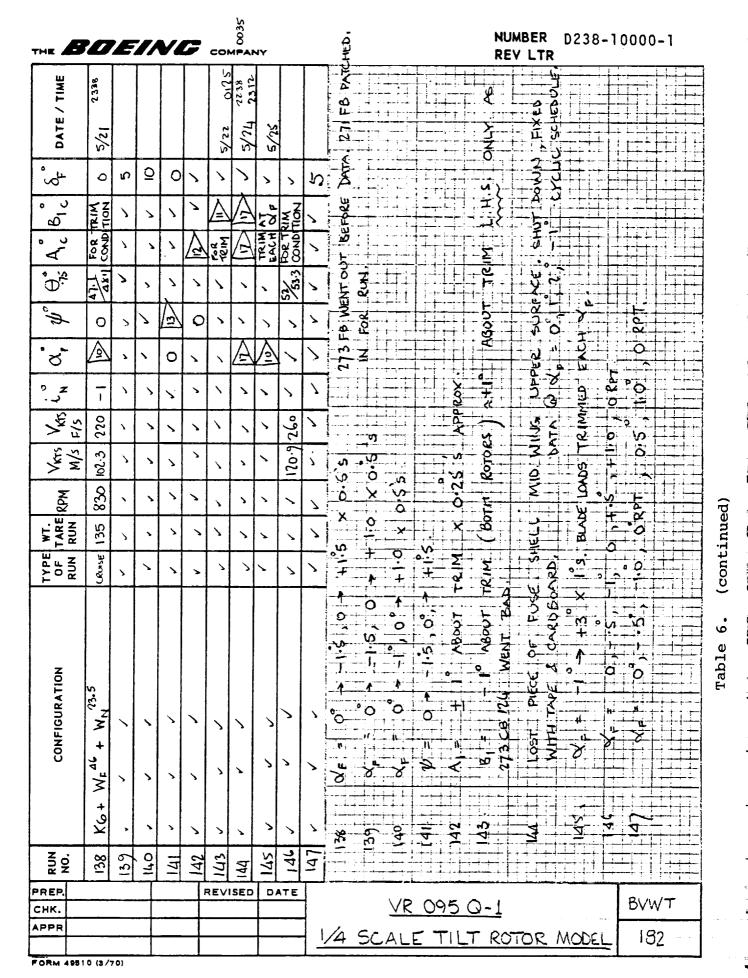
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RPM	830		1065	,	`	`	`	`	<u>\$</u>	200 + X X X X X X X X X X X X X X X X X X	
WT. TARE RUN	103	`>	89	, ,	/	`	>	•	\	30 1 2 0 0 2 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	-
TYPE OF RUN	ઉદ્યાપ્ટ	`	7	,	>	``	`	`			
CONFIGURATION	Kg + WF46	,		\ \			,			00 KP. S. R. S.	
RUN NO.	101	110	=	21	5)		-	٥	117	100 100 100 100 100 100 100 100 100 100	
REP.				L		1_	ISEC	<u> </u>	ATE	VP 095 0-1 BVV	
снк.							•	1	•	VR 095 Q-1	
APPR								4_		1/4 SCALE TILT ROTOR MODEL 18	2



HE B	Ø,	E	//	12	7	COM	IPAN'	Y		NUMBER D238-10000-1 REV LTR
DATE / TIME	6/20/					00	421 1017 129		2230	PKONISION PKONISION PKONISION PKONISION PKONISION
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/krs F/S	081	>	7	7	Ŋ	,	>	`	>	A S S S S S S S S S S S S S S S S S S S
VKrs M/s	83.7	7	,	,	1	>	`>		\	
RPM	830	,	7	>	7	7	>	`	7	
WT. TARE RUN	128	`	,	7	>	\	135	`	,	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TYPE OF RUN	CRUER	`	\	>	>	`	`	>	>	
CONFIGURATION	K6 + WE 46 + WM.7	,	7	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \		,	7 + W _N 23-5	, , ,		32
RUN NO.	129	130	131	152	3	134	135	136	137	
PREP. CHK.						REV	ISED	DA	TE	VR 095 Q-1 BVWT 1/4 SCALE TILT ROTOR MODEL 182

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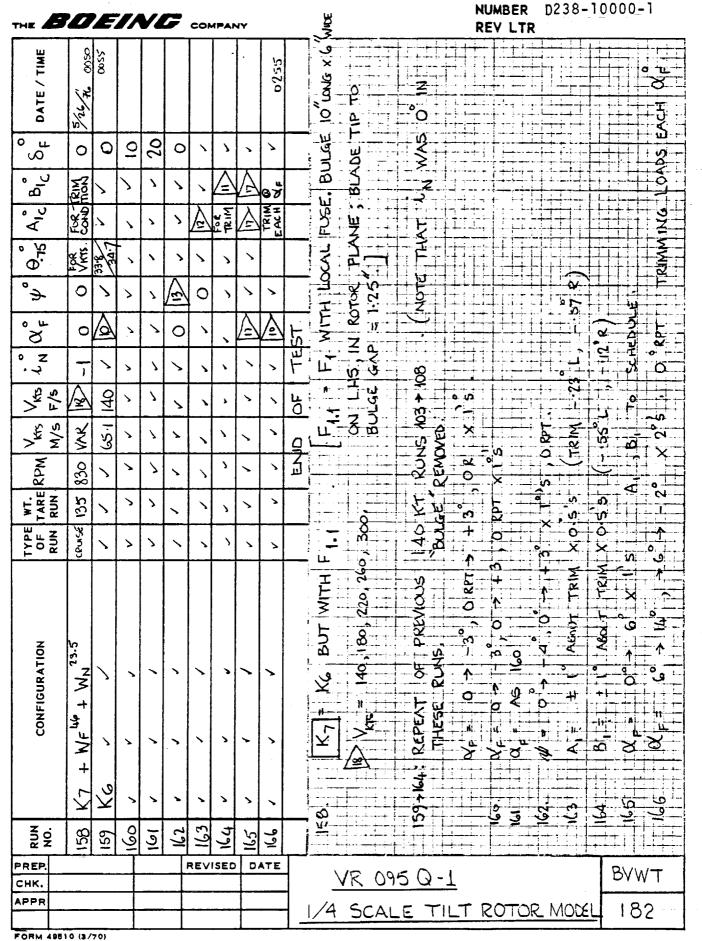
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HE B		Ę		V2	7	COM	IPAN	~			REV LTR
DATE / TIME	SIZS				0325	6/26/ 1945			2100	2133	
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	T K	`	Ā	A	RIM	,	>	7		A	
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> 75 S	260	7	7	`	300	>	,	\	`	`	
> Z Z Z S	િન્દ્રી	,	`	`	139.5	,	`	/	`	`	A S N C O T
RPM	835	/	>	`	`	`	`	>	۶.	`	
WT. TARE RUN	135	`	/	`	^	`	`	>	/	`	
TYPE OF RUN	CRUSE	`	/	,	`	,	`	>	>	>	
CONFIGURATION	KG + WF 46 + WN 23.5	, , ,	/ / /	, ,	1 1	, , ,	/ / /	\ \ \ \	, , ,	,	A = 0, 1.5, -1.0
RUN NO.	148	149	150	151	152	153	154	155	156	157	2
CHK.						REV	ISED	D	ATE]	VR 095 Q-1 VA SCALE TILT ROTOR MODEL 182

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SHEET 114

able 6. (continued)

Table 7. Summary of Configurations Tested and Configuration Con

Code	Configura	tion
к ₁	w ₁ F ₁ N ₁ T ₁ V ₁ H ₁	
K ₂	W ₁ F ₁ N ₁ T ₁ V ₁ H ₁ B ₂₆	88,208,328 3,266,265 B272,271,273 PL ₁
к ₃	W ₁ F ₁ N ₁ T ₁ V ₁ H ₁ B ₂₆	8,178,298 88,208,328 63,266,265 ^B 272,271,273 ^{PL} 1
К4	W ₁ F ₁ N ₁ T ₁ V ₁ H ₁ B ₂₆	8,178,298 88,208,328 63,266,265 ^B 272,271,273 ^{PL} 2
к ₅	W ₁ F ₁ N ₁ T ₁ V ₁ H ₁ B ₂₆	0,150,270 B60,180,300 PL ₂ 63,266,265 272,271,273
к ₆	W ₁ F ₁ N ₁ T ₁ V ₁ H ₁ B ₂₆	0,150,270 _B 60,180,300 _{PL2.1}
к ₇	W ₁ F _{1.1} N ₁ T ₁ V ₁ H ₁ B ₂₆	0,150,270 B60,180,300 PL _{2.1}

Table 8. Configuration Codes Components Description

- W₁ Wing
- F₁ Basic Fuselage
- N₁ Engine Nacelle
- T₁ Horizontal Tail
- V₁ Vertical Tail
- H₁ Basic Hub
- W_F²³ Lead tuning weight of 23 lb. fitted in front fuselage 32 ins. forward of model C.G. (Sta 40.613, WL 4.404) as defined by weight tares routine.
- WF⁴⁶ Lead tuning weight as defined by WF²³ with an additional lead weight of 23.5 lb. in the rear fuselage 31.5 ins. aft of the model C.G.
- ${\rm W_N}^{17}$ 17 lb. tuning weight fitted to each nacelle, comprising a 10 lb. calibration weight at 6 ins. aft of the hub center-line and 7 lbs. of steel supporting structure. (See Figure)
- $W_N^{23.5}$ Tuning weight as W_N^{17} , with 6.5 lb. of additional weight in the form of an aft weight support bracket (See Figure)
 - PL₁ Basic pitch link arrangement.
 - PL₂ Pitch link with barrel 2 ins. longer than PL₁.
 - PL_{2.1} Pitch link PL₂ with pitch arm rotated 20° to obtained higher values of collective pitch.
 - B_{XXX}^{YYY} Basic rotor blade. Rotor is defined as:
 - AAA,BBB,CCC , where XXX, YYY, ZZZ are the XXX,YYY,ZZZ

blade serial numbers and AAA, BBB, CCC are the respective azimuth locations in cyclic order with respect to the blade l/rev indication. (In the Config. Descriptions, the left hand rotor is identified first.)



- Table 8. Configuration Codes Components Description (Cont'd)
 - F1.1 Fuselage F1 with local 'Bulge' 10 ins. long x 6 ins. wide added to left hand side of the fuselage in the rotor plane, approximately on the fuselage £, to reduce the rotor/fuselage gap to 1.25 ins. (scaled full scale dim'n.).

4.2 Data Notes and Instrumentation Log

As with any test program, the circumstances of the test, condition of instrumentation, etc., have a direct bearing on the interpretation of the experimental data. The data obtained on this test program are contained in seventeen data files; each file containing the information pertaining to the initial condition of the same number as explained in section 4-1. The file reference system is explained in section 5.0 This volume contains data for the first four conditions. The rest of the data can be found in the Appendix. Volumes 2, 3 and 4 References 4, 5 and 6.

The instrumentation log of the test program is provided in table 9. It is the purpose of this section to point out those conditions which are known to have influenced the data.

Blade loads data were obtained from strain gage measurements at 0.125R. At least two blades were instrumented on each rotor although only one blade on each rotor was recorded on each test run. From time to time blade gage instrumentation failures required switching from one blade to another mid run or in order to complete a run sequence. These events are recorded in the log on a run by run basis.

The strain gage balance sensitivities are recorded and also variations in sensitivity made as a result of check calibrations (ETESC, end to end system checks). The total loads balance in

the model (BV-6049) was used for Runs 1 to 25. The SRH balance (BV-6054) was used in Runs 26 to 35 and then replaced by a short adapter and BV-6049 used for the remainder of the test.

Two six component balances were used to measure the rotor forces and moments, one in each nacelle. These balances are designated BV-6047 (left nacelle) and BV-6048 (right nacelle).

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On Run 82, the side force channel on the right hand balance was found to be saturating intermittently and causing the right hand rotor data to be spurious after processing through the balance matrix. Subsequent examination of the data showed that this problem occurred earlier and results in the right hand rotor data being invalid between Runs 68 and 96. The right hand rotor data are not plotted for these runs. nature of the problem was an intermittent connection at the gage itself on one of the side force flexures. This failure was not always apparent under static load and may have resulted in some error prior to Run 68. The right hand rotor data should be interpreted with some caution. If error was present, the yaw moment would be the most seriously affected. From Run 82 to Run 92, the right hand side force sensitivity was set to zero. For these runs the longitudinal force and moment measurements should not be seriously affected. From Run 96 on, the left hand side force channel signal was fed into the computer input for right hand side force with its sign inverted to

preserve sign conventions. For data runs subsequent to Run 96, the test conditions were symmetrical rotor behavior would be expected (e.g., α effects) should yield reasonable data on the right hand side. Where symmetry is not the case, the lateral data from the right hand side must be interpreted with caution.

During the 180 Kt. cruise data runs, the blade gage data contained unexpected harmonics and non integer responses. During investigative work, a flexible coupling in the drive system failed. Replacing the flexible coupling caused the wave forms to return to their expected shape. Similar phenomena were seen in the shaft torque wave forms. Blade loads data for the 180 Kt. cruise condition (Condition #14) are suspect insofar as the residual loads are probably artifically high as a result of the drive system problem.

	-						Γ	1	Γ	1	, ,								
	RUN		-	-	-	-	-	-			-	-	+	-	+	-	•	+	
	REMARKS		* TOTAL LOADS ALLOWABLE	PM VS RM ON SCOPE			PH VS RM ON SCOPE TMBAL & RM AC.	:			* TOTAL LOADS								
	d-d		2*	2	2	2	2	7			* 0	0	0	0	0	0			
	CEC															_			
2	SCOPE			7			77												
- 18′	COND		ō	20	60	40	90	8			21	15	14	13	81	Lı		32	
MS /	MPX AMP		ō	02	33	34	05	ઝ			16	15	14	(3	18	71		32	
MAR	MPX		H01	H02 L02	H03 L03	404 104	405 105	H N N N			71 H IC	H15 L15	H 14 L 14	H 13 L 13	H 18	47		787	
IDS NO	CEC VCAL																		
NTAT I	ALLOW CEC VOLTS VCAL																		
INSTRUMENTATION SUMMARY BYWT-182	ALLOW																		
9. IN	SENSITIVITY	AGE)	27.506	67.402	348 · 074	81.688	59.064	22 . 172		(LEFT NACELLE)	14.964	30.140	34.186	14 . 450	28.471	5.587		19.447	
Table	GAIN FILTER	(FUSELAGE)								(LEFT N									
	GAIN	BV-6049	-10 4000	1000	80	1000	1000	1000		BV 6047	000	\$	9	1000	4000	8		200	
	√B	BV-	9-	-lo	-15	-10	01-	-5		8	0	و	2	0	ڡ	૭		3	
	PARAMETERS	BALANCE	NFBAL1	PMBALI	AFBALI	SFBALI	YMBALI	RMBALI		BALANCE	NF BAL 2	PMBAL 2	AFBAL 2	SFBAL 2	YMBAL 2	RMBAL2		Qs2	

		ı		
	۹	ı		
•		7		

	REMARKS RUN		* TOTAL LOADS						-		L.H.S STEADY ON (P-P) METER 24	" " 24	11 24	RHS STEADY ON 24 (P-P) METER 24	" OUT RUN 48 24	
	c P-p		ō	ō	ō	ō	٥	ō			8	र्ठ		ß	8	
	SCOPE CEC										(H)	\\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\	(ဂ)၄	2н	2V 3L	
	COND		ō	60	80	10	2	11	31		22	23	24	61	20	
AMP	:		0	8	80	10	12	11	31		53	24	55	50	ত	7
	MPX		문의	H09	H08 L08	H01	22 1	==	163		H22	нз	н31	61H	Н20	L
	OW CEC TS VCAL										12	1.75	32	 19	\ 3	
_	ALLOW										± 3.12	て ノ	± 2·32	\$2.67	12.43	1
	ALLOW										± 70	443.5 1 15	10 STDY ± 20	÷ 70	SI T.	205TPY
	SENSITIVITY ALLOW	T NACELLE	15.347	30.177	37.210	14.750	29.716	5.990	19.364		22.470	19.978	8.625	26.200	17.895	
	FILTER	(RIGH	ᆂ	노	포	١K	<u>.</u> الح	¥			Ξ	포	ᆂ	포	포	
	GAIN	BV-6.04.B	8	8	200	1000	1000	<u>8</u>	500		500	200	500	200	200	-
	VB		2	ی	01	10	و	ی	 ಬ		ري د	2	5	\$	5	_
	PARAMETERS	BALANCE	NF BAL 3	PMBAL 3	AFBAL3	SFBAL3	YMBAL3	RM BAL 3	(453)	-	265CB12u	265FB124	26.5 PA	273CB124	273 FB124	1

	RUN	-	_	24	24	24		24	24	24	77	77	24	-	-	
	REMARKS							K'IN 9'8/VOLT.	н	af .	*	7	10	SHAFT ENCODER, DIRECT READOUT.		
	d-d															
	CEC															
2	COND SCOPE															
MT - 18'	COND	26	25	28	77	29		52	53	54	55	25	25		30	
, BM	MPX AMP	20	61	22	21	23		56	57	58	59	99	19		24	
MARY	MPX	120	617	122	121	123		H25	H2C	н27	H28	H29	H30		124	
N SUP	CEC															
NTATIO	ALLOW															
INSTRUMENTATION SUMMARY BVNT-162	ALLOW															
le 9.	SENSITIVITY	24.840	28.441	28.00	28.00	4.793		0.6805	1.0793	0.6542	0.6658	0.7135	0.6873	•	19.633	
Tab	GAIN FILTER							ا اج	포	포	포	ᆂ	万			
	GAIN	01	10	S.	5	01	55	8	8	8	00	100	100		5	
	V _B	2.5	2.5	-	0.1	2.0	LETE	ō	0	ō	2	ō	0	1	Ŋ	
	PARAMETERS	LEFT NACELLE	RIGHT NACELLE TILT (LN°)	LEFT FLAP ANGLE	RIGHT FLAP ANGLE	ELEVATOR ANGLE	ACCELEROMETERS	LEFT VERT.	LEFT LAT.	LEFT LONG	RIGHT VERT.	RIGHT LAT.	RIGHT LONG	PITCH ANGE (KNUCKLE)	YAW ANGLE (SRH)	

	j		Table	е 9.	STRUME	INSTRUMENTATION SUMMARY BYWT-182	MUS N	MARY	BVW	T-182					
PARAMETERS VB	A S	GAIN	FILTER	SENSITIVITY	ALLOW	ALLOW ALLOW CEC EU VOLTS VCAL		MPX AMP	AMP	COND	SCOPE	CEC	d - d	REMARKS	NS.
CONTROL SYSTEM	SYS	TEM													2
RH ACT. #I	,	-		1354				128 65	55	911					24
RH ACT #2	1	_		- 1379				12) 66	200	46					24
RH ACT #3	ı			- 1390				130	67	47					77
LH ACT #1	1	-		1326				1.25	75	42					24
LH ACT #2	(-		1351				12%	દ૧	43					24
L н АСТ #3	t			1392				127	64	4					24
60/REV														PC 124	-
1/REV														L.H.	-
SRH BAL	ANC	BALLANKE (BV-16054)	(4509)												
NF BALI	80	000	- KC	218.4598				HOI	ō	ō			2	THIS BALANCE REMOVED AFTER RUN 35 AND	26
PM BAL I	-5	0001	- KC	188. 2352					02	ળ	4		7	REPLACED BY 2"HIGH DUMMY.	26
AFBAL 1	8-	0001	-KC	285.0359					33	03			2		25
SF BAL 1	· 🕸	000	<u> </u>	1722 - 5071					34	ηO	•		2		77
YM BAL1	- 5	<u>80</u>	<u>ਨ</u>	187. 7934				H 06 L 05	છ	05	4		2		26
RMBALI	- 5	0001	IKC	156.6695				1 0 C	ठ	90			2		2

	RUN N	77	35	35	,		Eb 37	37	37	37	37	37		er 37	37	37	3 37	37
·	REMARKS	CHECK CALIB SENS.		5085 FOR 273 CB 124			BALANCE REINSTATED LOCKED OUT RUNS 34	→ 38. ACTIVE RUN 39 →						NEW SENS. POT RESET	2	:	OUT IN RUN 38	
	р-р						7	2	2	2	2	2						
	CEC																	
	SCOPE	5°	=	2Н				7			7						I	2H
T- 182	COND	14	22	61			ō	8	63	70	જ	૪		30			22	19
BVW	АМР	55	53	જુ			۵	70	33	34	05	૪		24			53	50
MARY	XdW	нэі	H22	нв			7 7 2 9	22 7 7	1 03 1 03	7 2 2 2	7 X 8	88 LE		177			H22	H19
N SUM	CEC												•					•
NTATIC	ALLOW VOLTS	‡ 3.5B	±2.98	\$ 3.30													± 2.76	±3.07
INSTRUMENTATION SUMMARY BVWT-182	ALLOW	τ_{p}	± 70	ol ‡													±_70	oŁ ‡
9.	SENSITIVITY	5.69	23.485	.21 - 233		BV- 6049 ~ (FUSELAGE)	27.506	67.402	348.0743	889 - 18	59.064	22.172		19.133	14.752	28.80	25.394	12.797
Table	FILTER	Ξ	포	포		2~(609	포	포	포	포	IK	ΙΚ					ㅈ	포
	GAIN	200	100	200		, 7 09	8	800	000	<u>000</u>	-10 1000	1000	_				200	200
	V _B	5	S	ഹ			-10	0001 01-	-15	우	9-	-5					λ.	J.
	PARAMETERS	265 PA	263 CB 124	या ८८ १८५		BALANCÉ	NFBALI	PMBALI	AF BAL I	SFBALI	YMBAL1	RM BAL 1		YAWANGLE	LEFT NACELLE	RIGHT NACELLE TILT CN.	163cB124	271 CB 124

ŀ		Table	9.	NSTRUME	INSTRUMENTATION SUMMARY BVWT -182	SUMMA	RY BV	WT -18	2			
A B	GAIN	FILTER	SENSITIVITY	ALLOW	ALLOW CEC VOLTS VCAL	EC MPX	X AMP	COND	SCOPE CEC	4-d	REMARKS	RUN
r)	28	구 구	5.125	120	€8.€ ∓	HZI	11 52	21	15			39
20	200	포	13.266	±70	± 3.01	нв	9 50	61	2н			39
-5	200	포	20.224	± 70	77.6 =	H22	12 53	22	(H)1		NEW GAUGE. REPLACED 263 CB121	3,
72	200	두	17 . 288	143.5	78.3	H23	3 54	23	3/2 2/2		RENDRIKED GAUGE WENT BAD IN RUN	ર્જ
22	500	포	16.072	+43.5/ +15		H13	3 54	23	∑. (3)		REPLACED 265 FB124	33
2.5	5		27. 481			7.00	92	20			NEW POT, REPLACED BROKEN ONE	39
				113.5/	\ \frac{1}{12}						OF DE STATE OF DESCRIPTION	
Ġ	200	포	15.83	\$ 15	\$6.	И30	2	2	بر گارد		(WENT OUT IN RUN 48)	49
R	200	Ξ	26.5	± 70	±2.67	н	9 50	61	2H		GAUCE, REPLACING 271CB.	49
											•	
오	2		26.85			121	21	li				\$
2.5	0		27.522			120	20	97	-		REPLACEMENT POT.	54
2.5	0		29.276			617	61	25			CHECK CALIB.	8
9	5		29.478			171	1 21	17			2	54
					•••						-	

·	REMARKS RUN	GAUGE 54	NEW GAUGE WENT OUT ROW 72 54	14UGE 54	NEW GAUGE.		Sens. 5		SENS, FROM 63		REPLACED 265CB124 72	265 FB 124 73	SENS. 82	COMPOWENT SATURATING 82 INTERMITTENTLY. SENS. 82		LH SFBAL 2 OUTPUT 96 TO SFBAL 3 CHI SENS. 96	NEW GENS.(ETESC) 96 (OUT RUN 115)	\documents
	p-p REI	NEW G	NEW G	NEW GAUGE	NEW GAUGE (213 REGAUGED B		NEW		NEW SE	·· — · · · · · · · · · · · · · · · · ·	REPLACED 265 (BAD SPIKING	REPLACED	New S	COMPONEN INTERMITY SET TO 'O'		LH SFBA! TO SFBAL!	NEW GENS.(ETE	:
	CEC														, , <u>,</u>			
7	SCOPE	1	\\\ \\\	2% 3L	2н				24		ΙН	7/30					5u	ž
Т-18⁄	COND	22	23	20	19		25		19		22	23	15	ω		Lo	24	2
MA /	AMP	53	54	51	ß		61		50		53	54	61	LO		Lο	65	3
WMAR	MPX	H22	H23	H20	НЮ		617		H19		H22	Н23	617	H67 [6]		H07	H31	H21
IIS N	CEC VCAL					•						•						
NTATIO	ALLOW CEC VOLTS VCAL	± 3-59	272	1.75	± 3.20				± 3·36		± 3.3¢	12.99					3.247	1.907
INSTRUMENTATION SUMMARY BYWT-182	ALLOW	0/ į	143.5	143.5	or ±			·	¢ 70		170	43.5					o1 ∓	707
9. IN	SENSITIVITY	19.61	16.02	15.84	21.85		31.546		20.83		20.856	14.54	29.449	0		- 14.45	6.16	800
Table	FILTER	포	노	ΙĶ	¥				天		포	я		본		포	ΙK	Ā
	GAIN	200	200	300	200		0	*********	200		200	200	<u>o</u>	8		000	2009	500
	V _B	Ç	5	S	-5	-	2.5		5		S	5	 2.5	0		2	5	5
	PARAMETERS	265CB124	165 FB124	273 FB124	271 CBIZL		RIGHT NACELLE		271CB124		263 CB 124	763FB124	RIGHT NACELLE	SF BAL3		SF BAL3	265 PA	272.00

	S S	8	3	60	603	103	103	103	Ξ	48	118	128	128	17.8		38	135	
	REMARKS	Por RESET TO GIVE SE READOUT. RECALIB.		NEW CALIB.	NEW SENS.	NEW SENS.	REPAIRED GAUGE		ABJUSTED SENSITIVITY, FROM ETESC	=	Sens. SET TO O. LN PUT IN AS INTERCEPT +	ADJUSTED SENS.	REPLACED 273FB124 AS THIS V. NOISY	PICKED UP AGAIN AS ZIIFBIZL OUT. O.K.NDA	961 804 136	REPLACED 273 CB124 WENT OUT THIS RUN. NO	-	Pur ou Scope vs W
	<u>д</u> -д								 									
	CEC														<u> </u>			
2	SCOPE				2H	2%/2 //32L	ī	\vert_32	> 3°	>/ \%		2 H	21/31	3/3/2		2H	2H/5L	
II- 18	COND	82	25	25	61	20	22	23	23	23	25	61	8	20		61	61	
BY	AMP	22	1	61	S	ī	53	54	54	24	61	50	2	21		50	જ	
MARY	MPX	111	730	617	H19	02H	127H	H23	нв	173	617	H19	Н20	138		HI9	61H	
AN SIL	CEC					•												
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INSTRUMENTATION SUMMARY BVWT- 182	ALLOW				± 70	143.5	± 70	143.5	143.5	143.8		± 70	143.5	143.8		470	01 ÷	
9.	SENSITIVITY	18.15	0	28.674	20.80	14.63	20.86	14.54	12.55	14.54	0	18.40	15.83	14.54		13.78	18.40	
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	R UN	88	144	144	144	144	14.4	441	144	53				
	REMARKS	REPLACED 273 FB124 (OUT BEFORE DATA)	NEW GAUGE ADOLD TO BLOPE VE W	NEW GALVAGE		NEW GAUGE	MEN GAUGE THIS WENT OUT ON SETTING		NEW GAUGE REPLACED 173 FB 124, GUESS SENS	REVISED SENS. AFTER ETESC (of 15.0 ABVE)				
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T-182	COND	20	22	23	24	61	20	21	20	20				
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MAR	MPX	H20	H22	H23	нзі	419	H20	H2]	H20	H20				
SIS N	CEC				•									
NTAT 10	ALLOW VOLTS	27.5	± 4.11	1.11		± 3.45	20.04 21.12		12:30	17.82				
INSTRUMENTATION SUMMARY BYWT-182	ALLOW	72	± 70	143.5		OL ∓	143.5		143.5	143.5				
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5.0 DATA FILE SYSTEM

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The nature of the test program where twenty-four quantities were measured against seven variables at seventeen conditions, was such that the test data produced required a system of filing to allow orderly usage of the information. The data are presented in seventeen data files, each file corresponding to an initial flight condition as shown previously in figure 54.

The data obtained in transition (Conditions 2 through 12) are presented in the order shown in table 10. All of the measured quantities which are comprised of the six components of the left rotor balance, the right rotor balance and the total loads balance followed by the blade data are first plotted against angle of attack α° and then the sequence repeats with yaw angle as the independent variable and so on. This sequence of results is maintained except where data are not presented due to instrumentation difficulties as described in section 4.2.

The hover data in data file 1 are given in a slightly different format. The measured data are in the same order as for the transition information and are first shown as functions of collective pitch followed by cyclic pitch effects at two thrust settings.

In cruise (data files 13 through 17) the measured data are first plotted against α for various flap settings as shown in

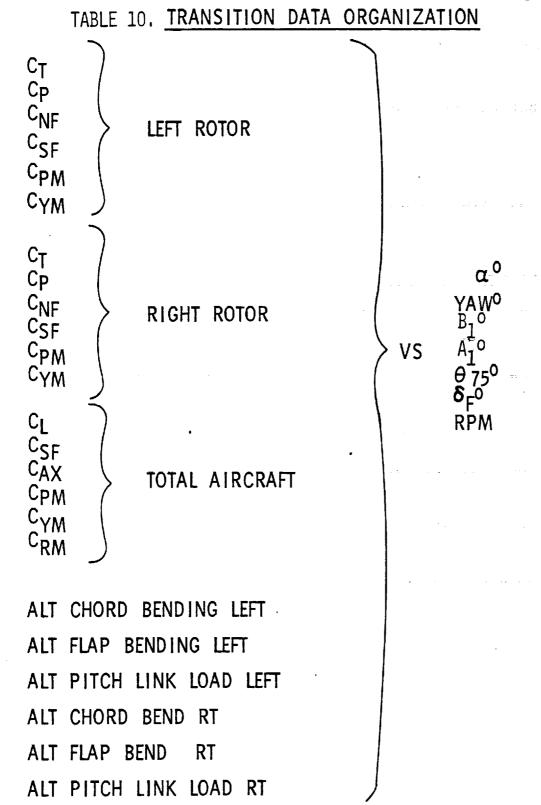


table 11, followed by yaw and cyclic pitch variations.

Only the blade loads data and control settings data are given for the combined α and cyclic runs at the end of each file.

The data provided in this volume are in the following files.

Data File 1 $I_N = 90^{\circ} V_{FULL SCALE} = 0$

₹

Data File 2 I_{N} = 90° $V_{FULL\ SCALE}$ = 45 Kts.

Data File 3 $I_N = 90^{\circ} V_{FULL SCALE} = 100 \text{ Kts.}$

Data File 4 I_{N} = 70° $V_{FULL\ SCALE}$ = 45 Kts.

Volume II presents data files 5 through 8.

Data File 5 $I_N = 70^{\circ} V_{FULL SCALE} = 100 Kts.$

Data File 6 $I_N = 70^{\circ} V_{FULL SCALE} = 140 \text{ Kts.}$

Data File 7 I_N = 50° $V_{\rm FULL}$ SCALE = 100 Kts.

Data File 8 $I_N = 50$ ° $V_{FULL\ SCALE} = 140$ Kts.

Volume III presents data files 9 through 12.

Data File 9 $I_N = 30$ ° $V_{FULL\ SCALE} = 100$ Kts.

Data File 10 I_N = 30° $V_{FULL\ SCALE}$ = 140 Kts.

Data File 11 I_N = 30° V_{FULL} SCALE = 180 Kts.

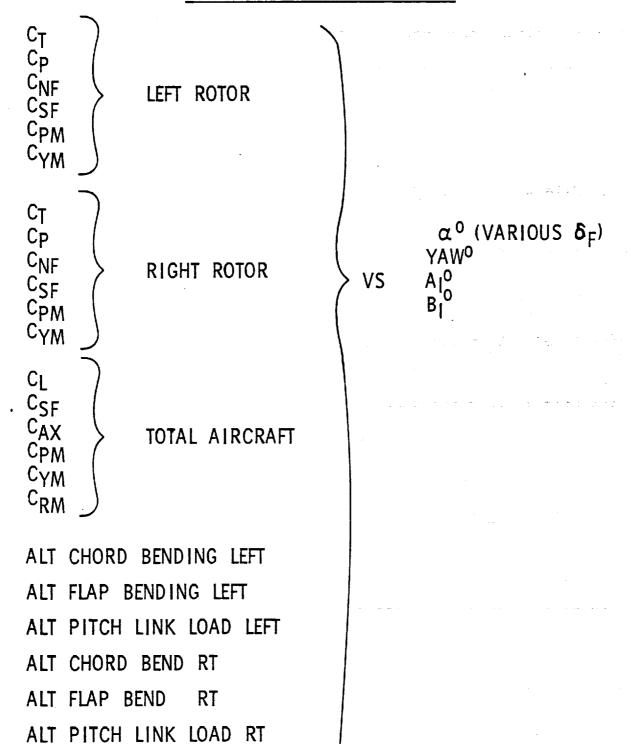
Data File 12 I_N = 15° $V_{FULL\ SCALE}$ = 180 Kts.

The cruise data files 13 through 17 are presented in Volume IV.

Data File 13 $I_N = -1^{\circ} V_{FULL SCALE} = 140 \text{ Kts.}$

Data File 14 I_N = -1° $V_{FULL\ SCALE}$ = 180 Kts.

TABLE 11. CRUISE DATA ORGANIZATION



BLADE LOAD AND
CYCLIC PITCH DATA

VS COMBINED α

Data File 15 I_N = -1° V_{FULL} $_{SCALE}$ = 220 Kts. Data File 16 I_N = -1° V_{FULL} $_{SCALE}$ = 260 Kts. Data File 17 I_N = -1° V_{FULL} $_{SCALE}$ = 300 Kts.

One further set of information is needed to allow the reader to use the information presented. It is necessary to know the constant values of test variables during each parametric variation. Each of the data plots list the nacelle angle full scale airspeed simulated, fuselage attitude and flap setting on the plot. The other variables (e.g., cyclic settings collective pitch, etc.) can be obtained by reference to tables 12 to 15.

For example, during an angle of attack variation in data set 3, the control settings pertinent to that run can be obtained by reference to table 12 and reading the values of the control parameters as:

V _{FULL} SCALE	100 Kts.
I _N °	90°
RPM	1183
^θ 75 left rotor	12
Al left rotor	4.1°
Bl left rotor	6.2
$^{\delta}$ F left wing	70°
$^{ heta}$ 75 righ t rotor	11.3°
Al right rotor	5.2°
^B l right rotor	6.8°

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3

 $\delta_{\mathbf{F}}$ right wing 70° 8 yaw angle 0

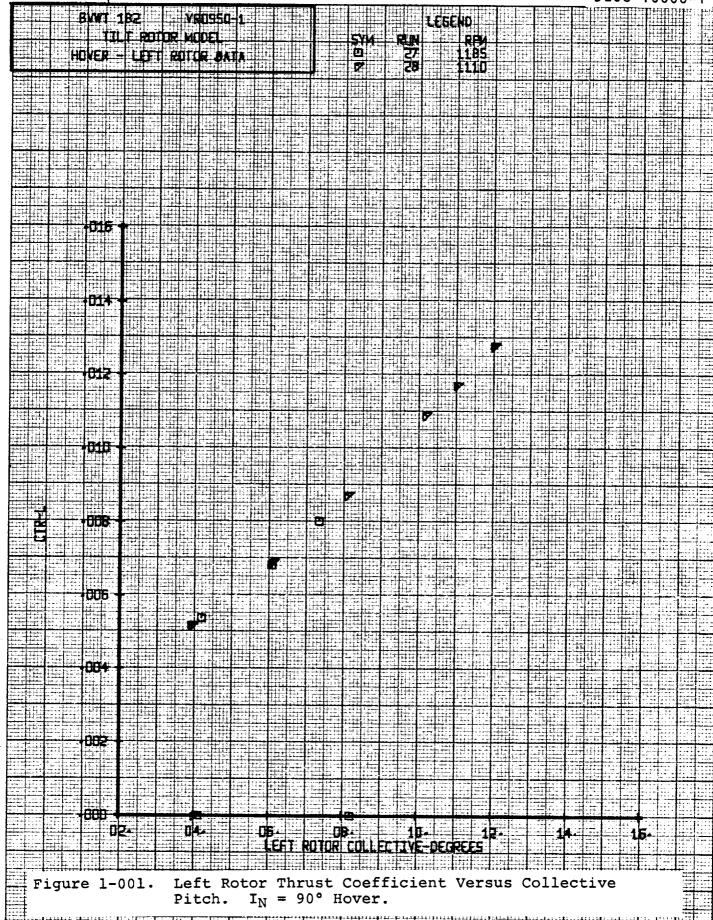
The tables pertinent to the data sets provided in volumes II, III and IV, are reproduced in those volumes for convenience.

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	PARAMETER VARIED	0.75 0.75 LONG. CYC. LAT. CYC.	YAW ANGLE LONG. CYC. LAT. CYC. 6.75 éFLAP RPM	α YAW ANGLE LONG. CYC. LAT. CYC. θ.75 δ FLAP RPM	α YAW ANGLE LONG. CYC. LAT. CYC. 6.75 δ FLAP RPM
	CONDITION	HOVER I _N = 90°	TRANSITION IN = 90° VFS = 45 KTS	TRANSITION IN 90° VFS = 100 KTS	TRANSITION IN = 70° VFS = 45 KTS

TABLE 12. CONSTANT VALUES OF TEST VARIABLES

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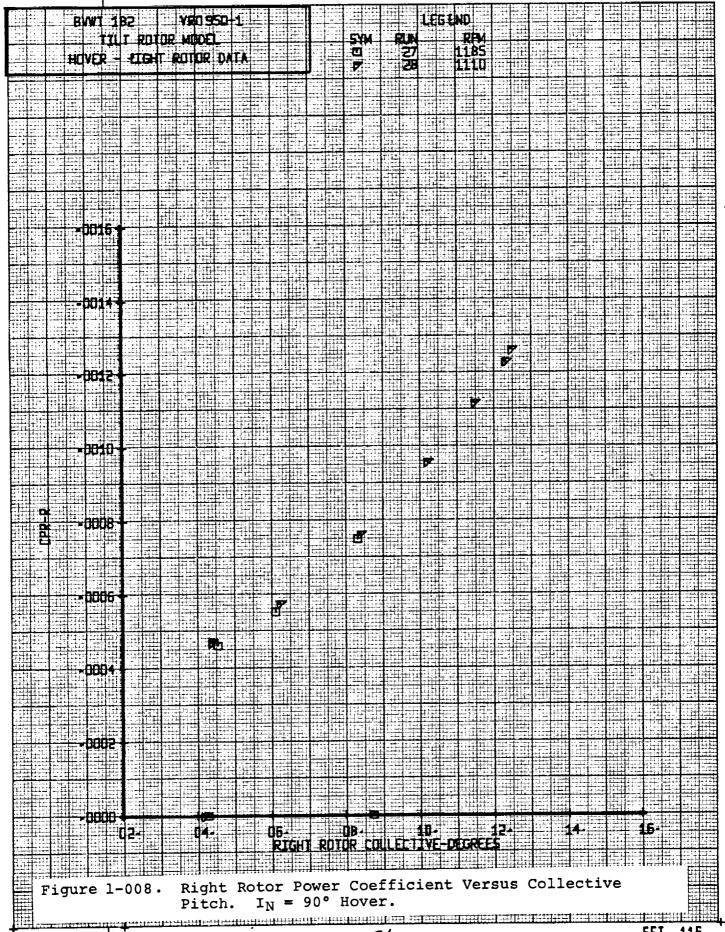
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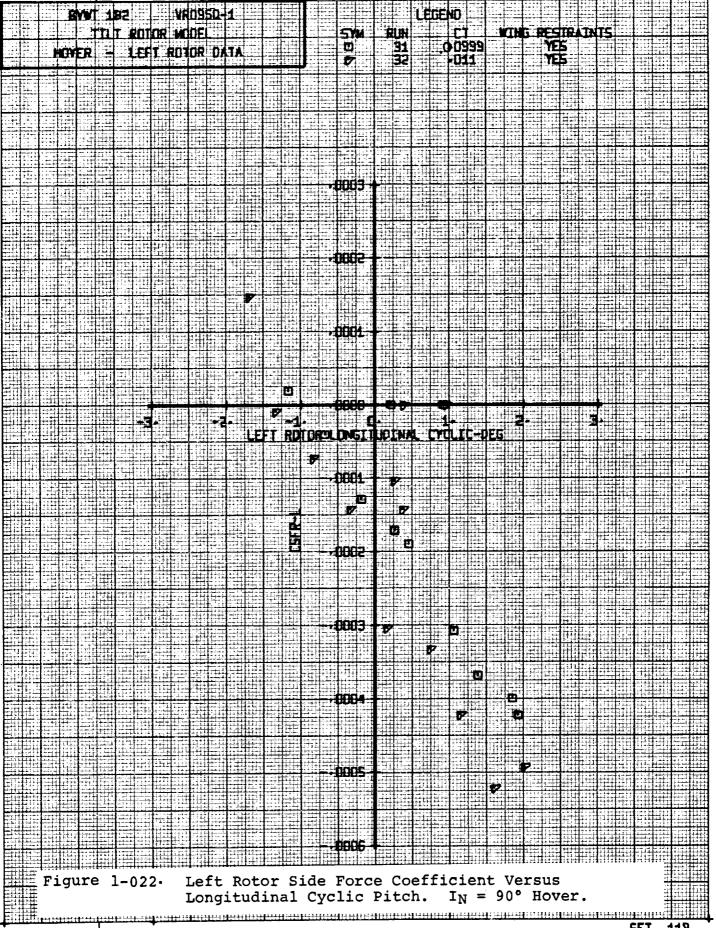
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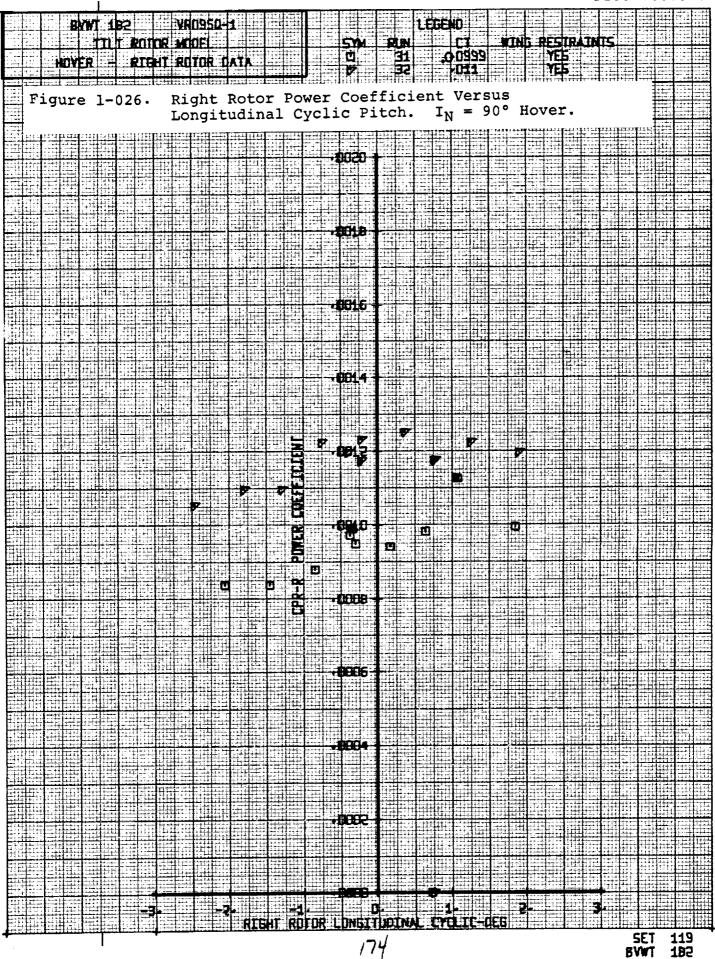
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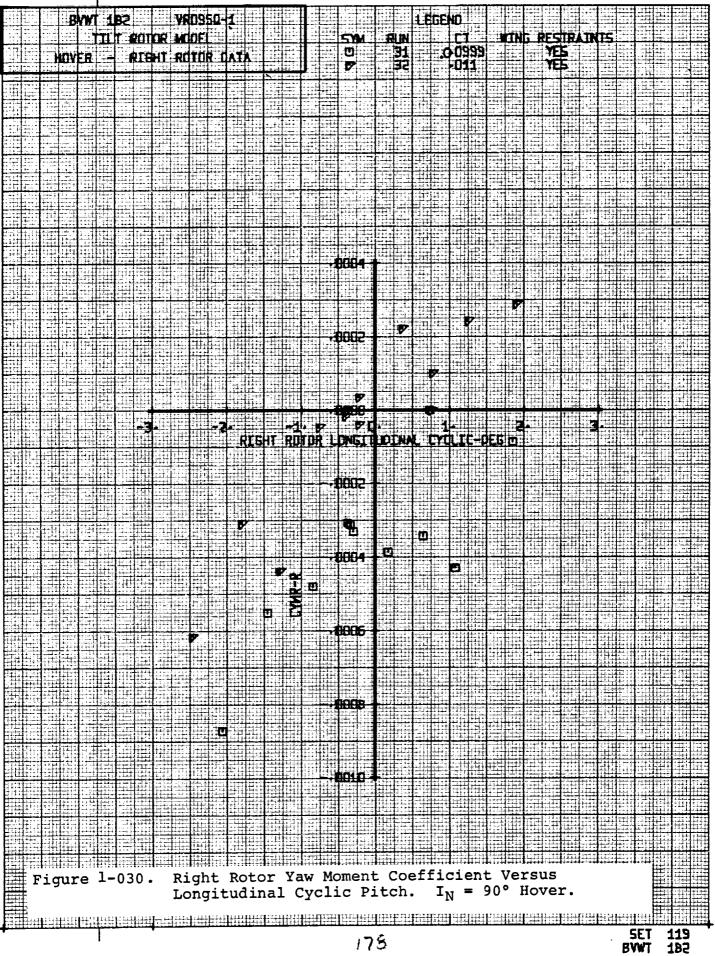
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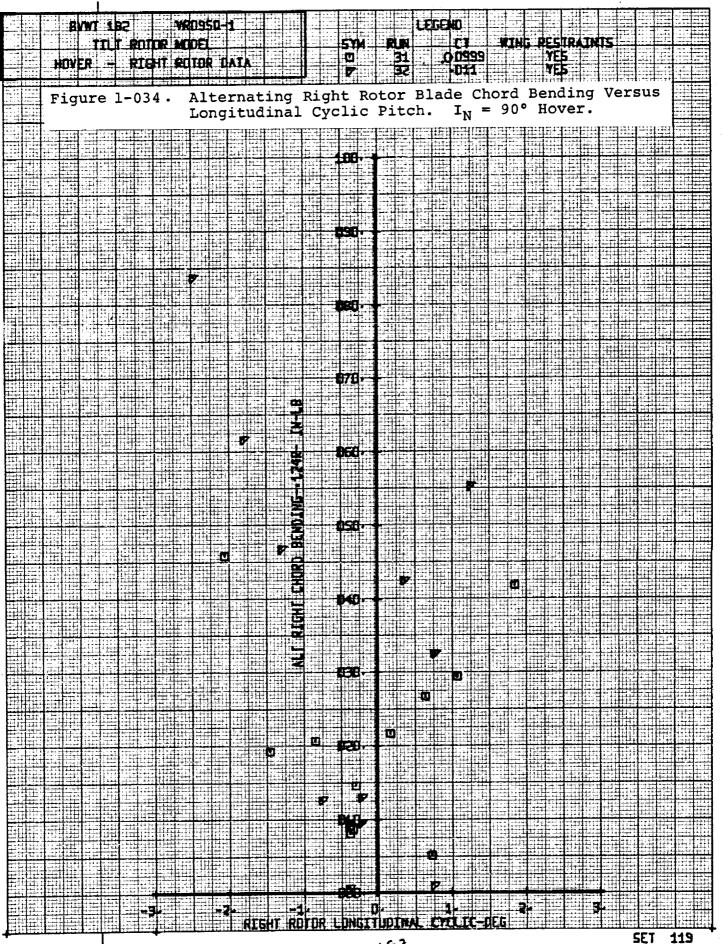
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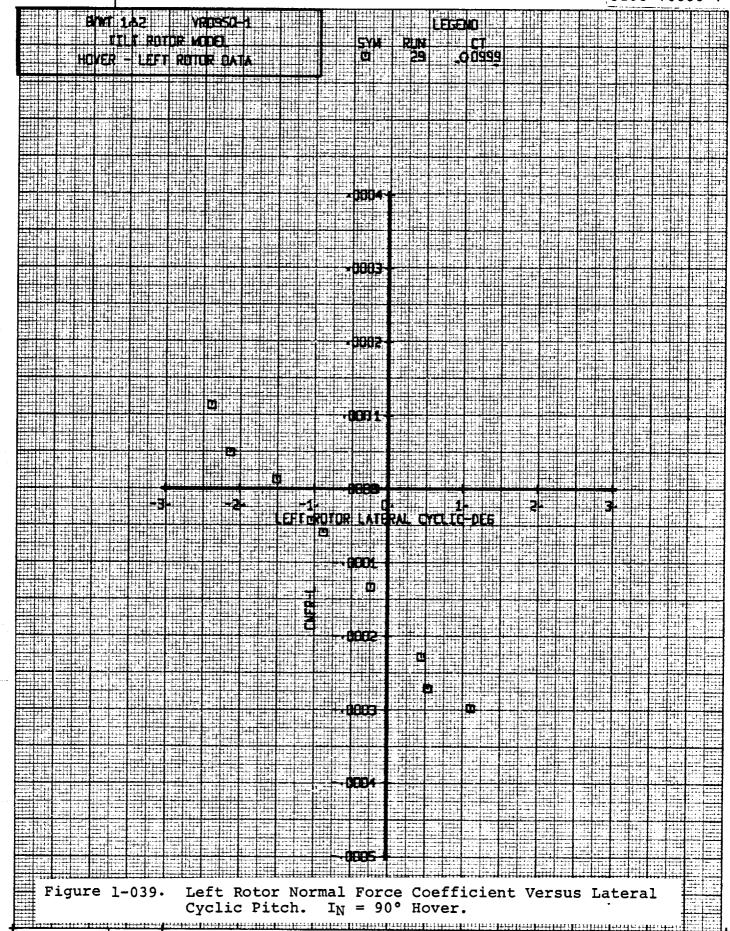
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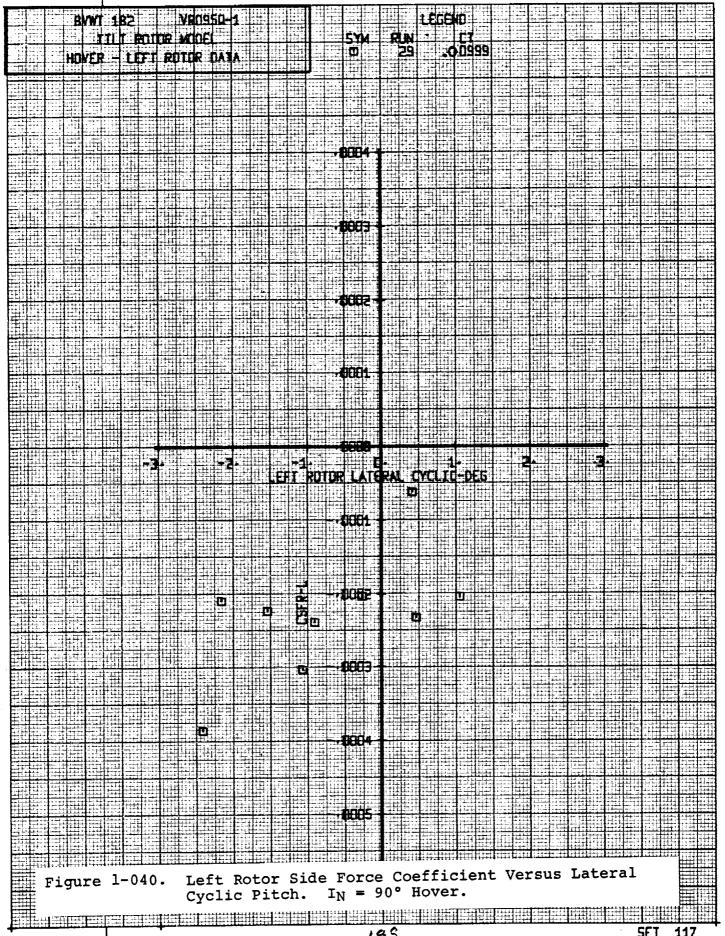
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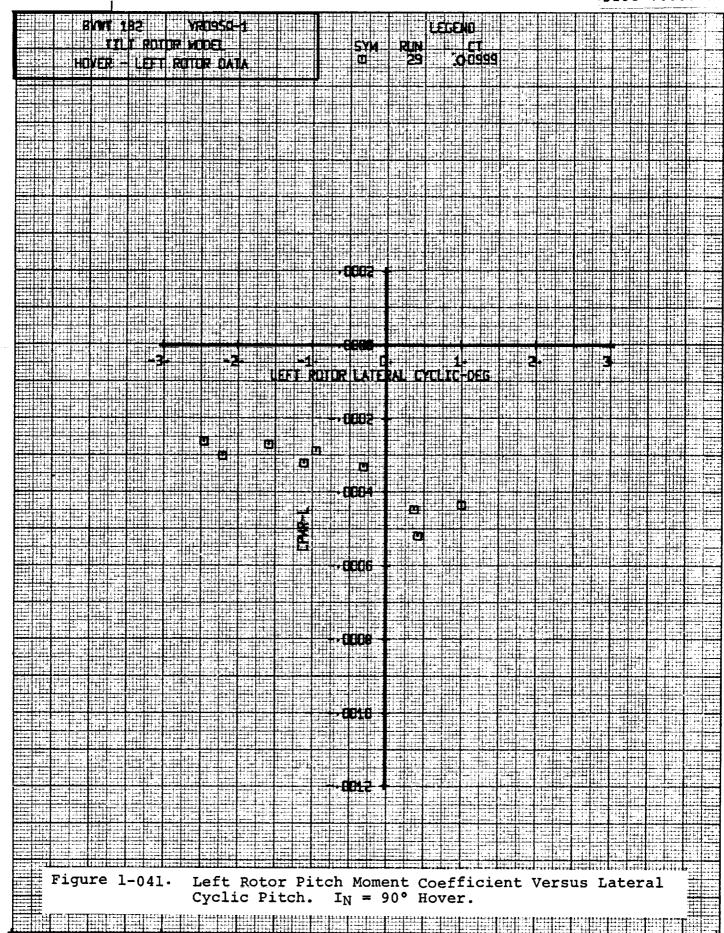
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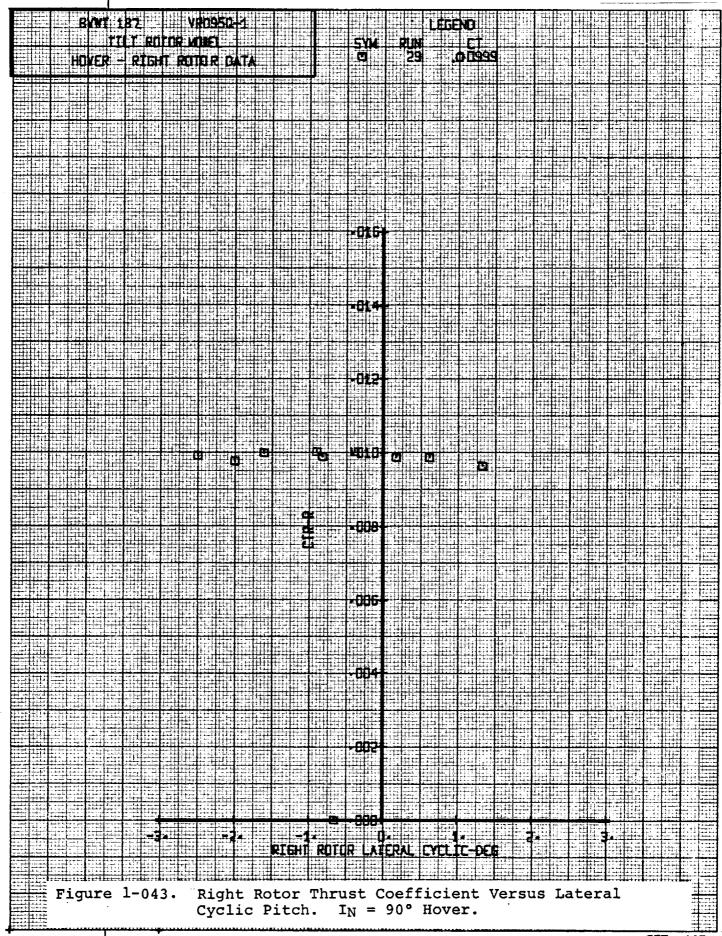
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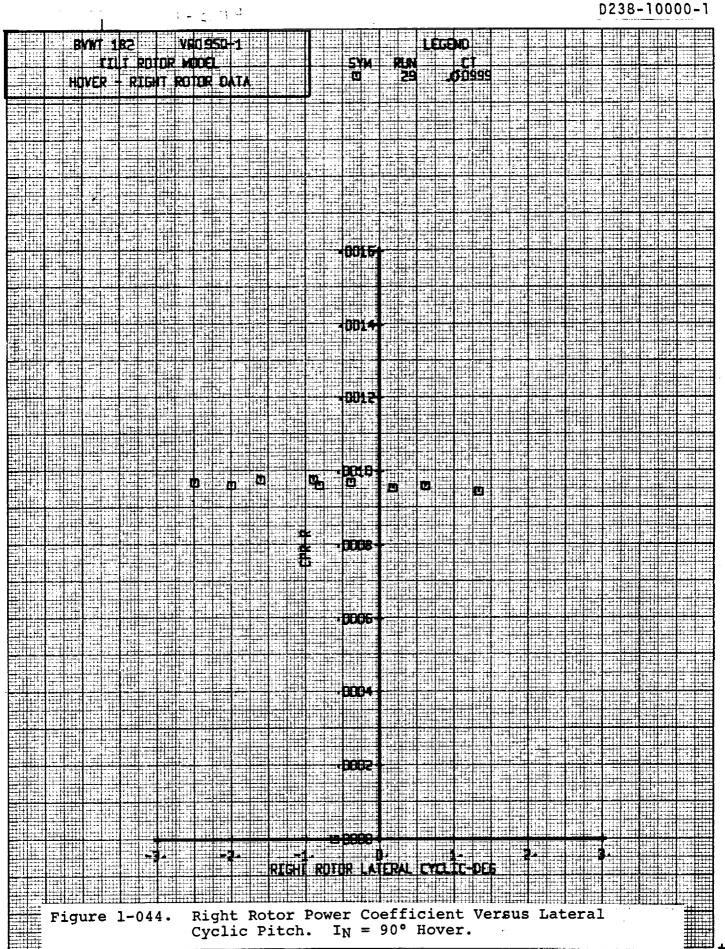




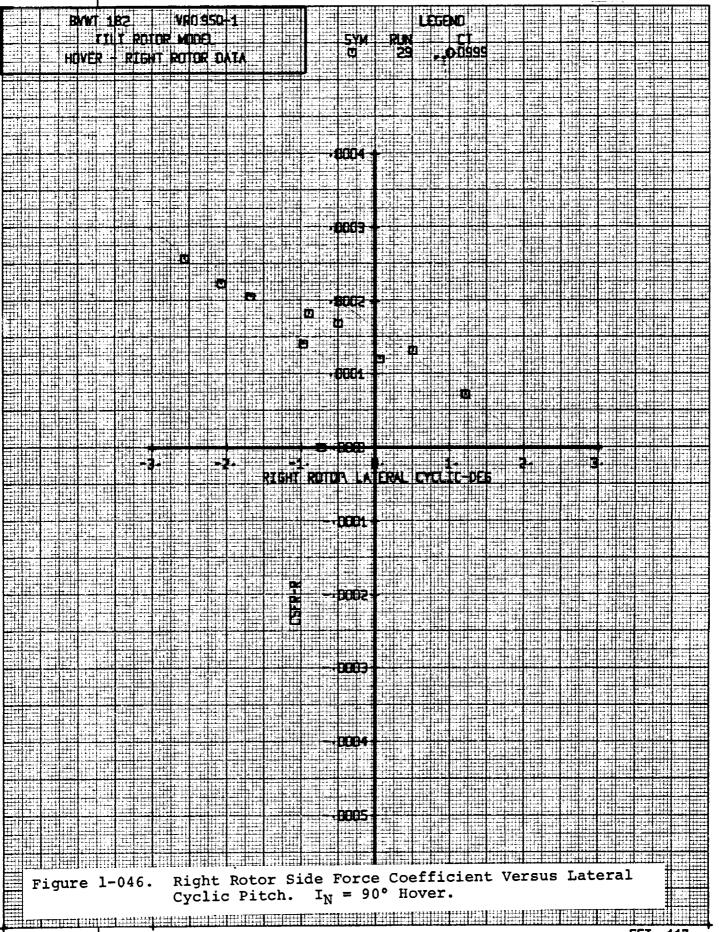
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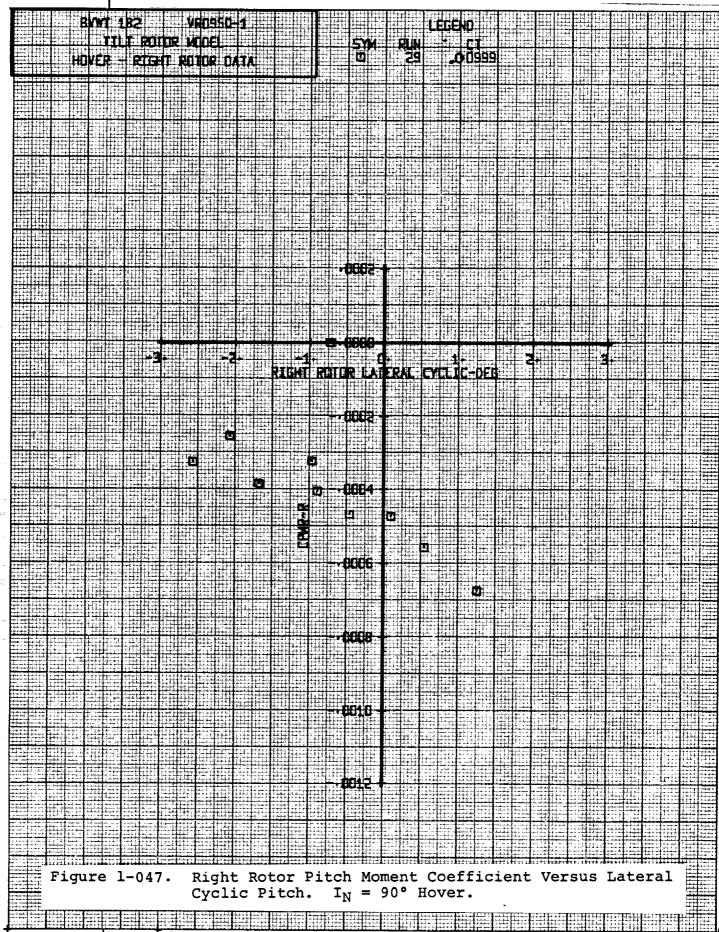


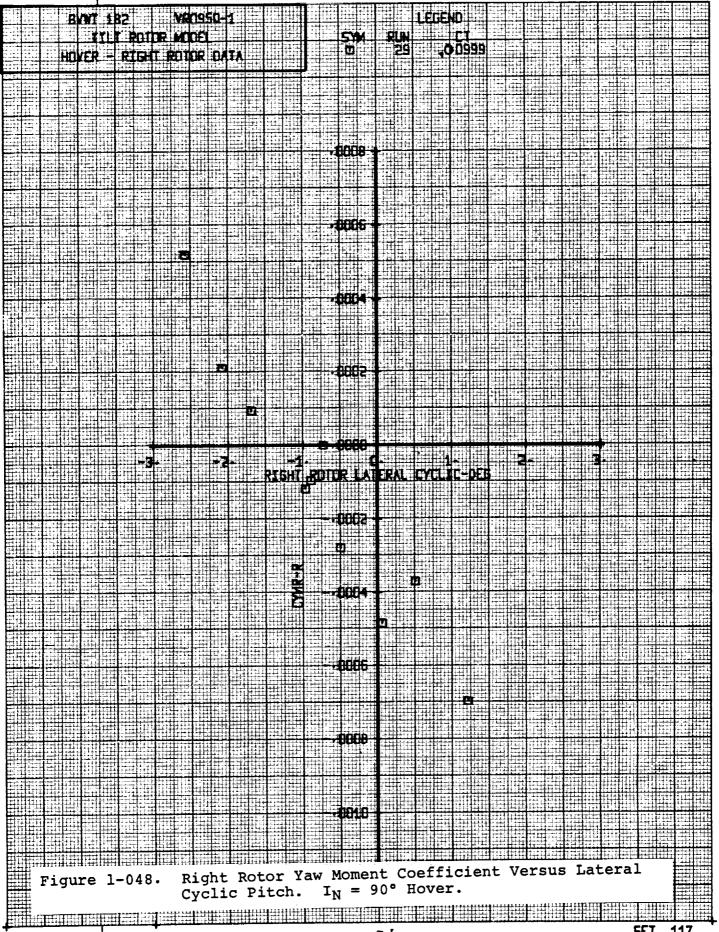
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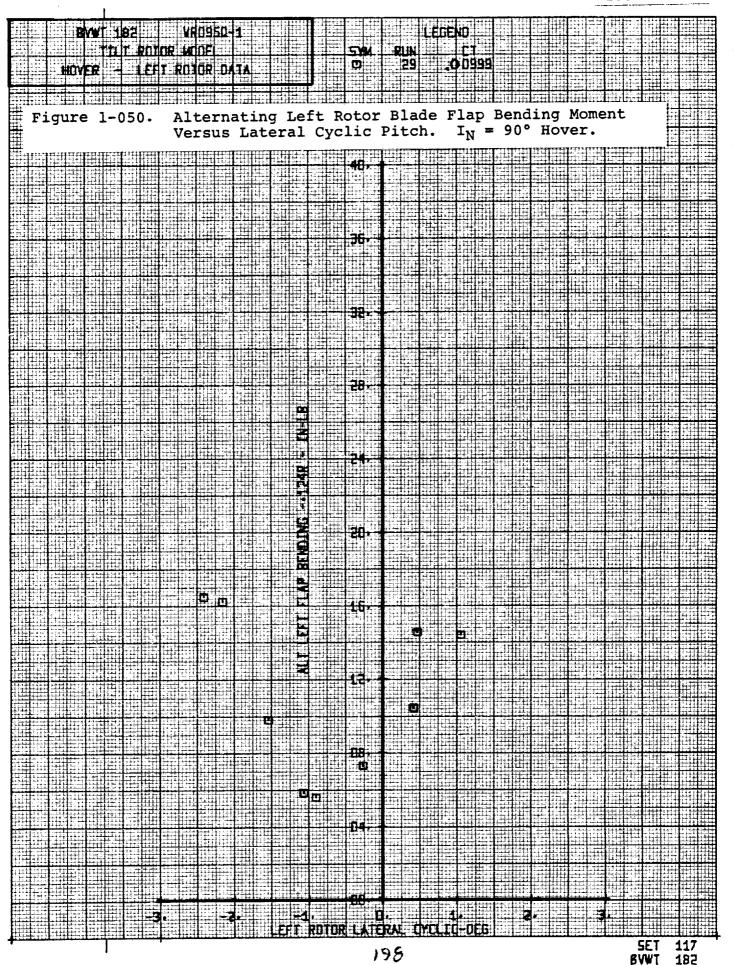
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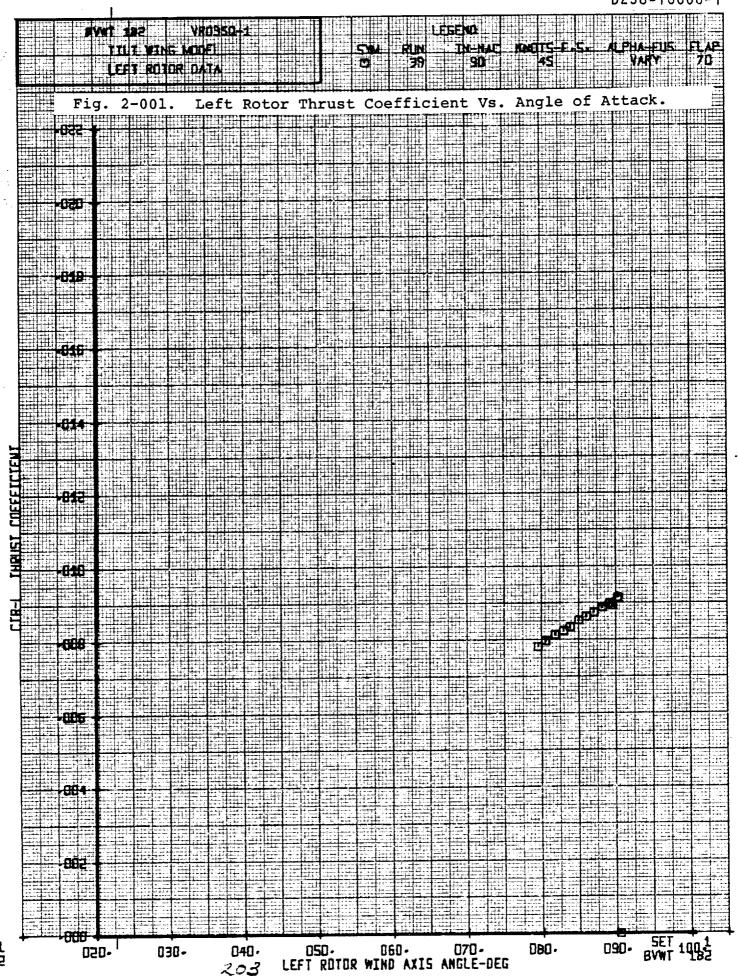
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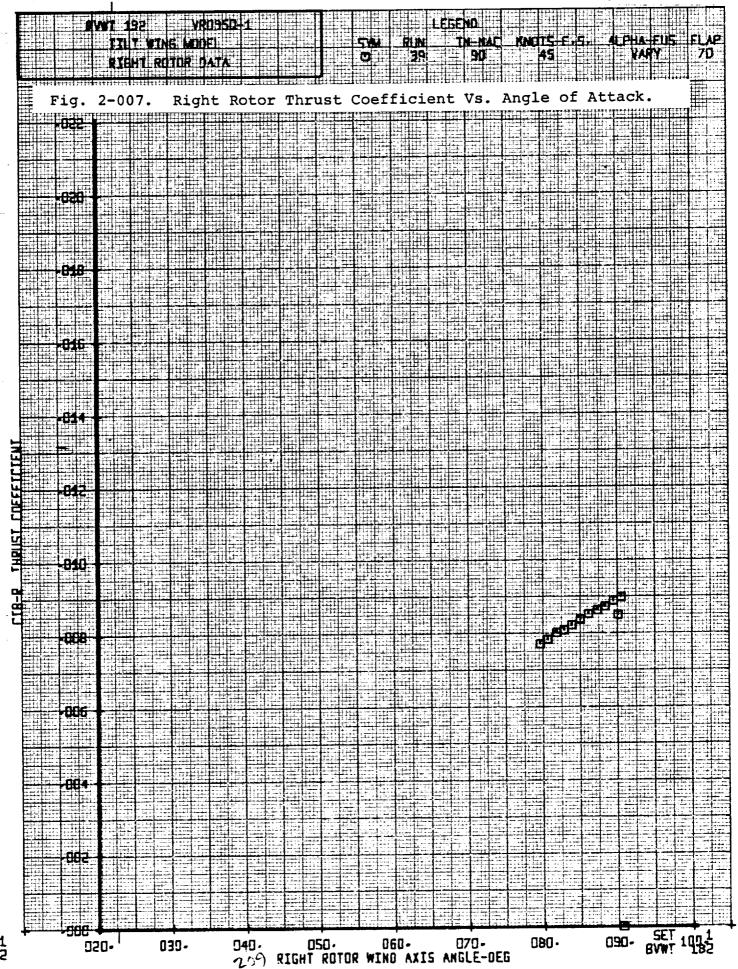
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